

**AN INVESTIGATION OF A PROPOSED
PLAN FOR CONVERSION OF
LIBERTY SHIPS**

**William D. Ball, Jr.
and
Charles Scott Marple**

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1954

THESIS
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PLAN FOR CONVERSION OF LIBERTY
SHIPS

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AN INVESTIGATION OF A PROPOSED PLAN
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by

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(1945)

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SUBMITTED IN PARTIAL FULFILLMENT

OF THE REQUIREMENTS FOR THE

DEGREE OF NAVAL ENGINEER

at the

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

June, 1954

ABSTRACT

AN INVESTIGATION OF A PROPOSED PLAN FOR CONVERSION OF LIBERTY SHIPS

by

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U. S. Coast Guard

Charles Scott Marple, Lieutenant,
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Submitted to the Department of Naval Architecture and Marine Engineering on 24 May 1954 in partial fulfillment of the requirements for the degree of Naval Engineer from the Massachusetts Institute of Technology.

The object of this thesis is to present a conversion plan for the existing Liberty Ships involving least cost to increase their potential as a national defense investment by increasing their speed to 15 knots. Approximately 1500 Liberty Ships are now in the reserve fleet, costing originally upwards of Six Billion Dollars. They are regarded as obsolete and a questionable defense potential because of speed limitations.

This proposal is based on the following: Scrap one ship and save propulsion machinery; modernize one ship by using the additional propulsion machinery obtained to double the power, and lengthen the bow 24 feet to improve resistance.

Details of machinery changes: Move forward engine room bulkhead forward 17' 6" to make room for the two additional boilers; mount two main engines each 6' 6" from the centerline of the ship in the same longitudinal location with the starboard engine HP cylinder placed aft so that the engine driven auxiliaries and main condenser retain the same position relative to this main engine; install single reduction gears for engine speed of 76 RPM to 85 RPM of propeller; use new line and tail shafting, new stern tube, and new 18' propeller; necessary auxiliaries duplicated using those from scrapped ship.

The new bow is faired into existing Station No. 3 at approximately frame 30 and has the following characteristics: Cut-up starting at 53' 7" from new forward perpendicular, 20° raked stem, and 16° half angle of entrance.

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Final characteristics of conversion:

Length between perpendiculars = 440'	IHP = 5000 horsepower
Beam, molded = 56.9'	Speed = 15 knots
Draft = 27.15'	Range = 17,500 miles
Displacement = 14,175 tons	Deadweight = 10,300 tons

The conversion is considered feasible in spite of excessive fuel consumption, and would cost approximately One and One Half to Two Million Dollars per ship.

Recommendations for making this proposal an actuality:
Self propulsion model test; necessary detail designs for contract plans.

Thesis Supervisor: J. A. Brown
Title: Professor of Naval Architecture and Marine Engineering

Cambridge, Massachusetts
May 24, 1954

Secretary of the Faculty
Massachusetts Institute of Technology
Cambridge, Massachusetts

Dear Sir:-

In accordance with the requirement for the Degree of Naval Engineer, we submit a thesis entitled:-
"An Investigation of a Proposed Plan for Conversion of Liberty Ships".

ACKNOWLEDGEMENTS

The authors wish to acknowledge their indebtedness to Professor J. A. Brown, CDR, USN, Massachusetts Institute of Technology for his help and criticism in the course of this investigation. We also thank Professor L. Troost, Massachusetts Institute of Technology for his advice and encouragement; Professor Evers Burtner, Massachusetts Institute of Technology for his helpful comments; the major shipbuilding companies who aided us in cost estimates, although their names are withheld by request; and Mr. Walter Leavitt for his typing of the final report. Finally, we thank those members of the Naval Architecture and Marine Engineering Department who contributed beneficial comments when the impossible seemed evident.

The basic idea of using material from scrapped ships for this investigation was taken from a letter dated 7 August 1953 from Professor L. Troost, Massachusetts Institute of Technology to Senator Charles E. Potter, Chairman, Special Subcommittee on Maritime Subsidies.

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I. INTRODUCTION

The United States Government is in a dilemma, what to do with the Liberty Ships? These ships in their present condition represent an undeveloped potential of strength in case of national emergency.

Preceding and during World War II, the United States built approximately 1,500 Liberty Ships costing about six billion dollars. These ships, in fact, were considered obsolete when they were built. Slow and out-dated as they were, they did accomplish the job of logistic support in a creditable fashion.

Now laid up and rusting in reserve fleets their potential as a defense investment is questionable. Two alternatives are open to the Government; either to convert these ships so that they will be of use in a national emergency, or to scrap them. The former alternative seems more realistic. Not only would the Government realize greater strength in an improved fleet, but also work, which is desperately needed, would be available for the shipbuilding industry. The second alternative would represent a terrible loss. This thesis will concern an investigation of a conversion plan designed for national emergency only.

The basic premises for this investigation are: that at the beginning of such a period considerably larger numbers of ships would be required; that materials and machinery would be in short supply; and that there would be a time delay for shifting from peace time to war time production; i. e.

mobilization. The conversion plan fits itself to these conditions in that a minimum of material would be required; considerable scrap would be made available for the steel mills; and a number of modernized Liberty Ships would be available for immediate shipping requirements at a minimum cost.

Briefly, the conversion plan embodies the following features. For each ship modernized, one would be scrapped, except for the propulsion machinery. By using the salvaged machinery to double the power in the converted ship, its speed could be increased. Modification to the bow by lengthening is proposed to reduce resistance and provide a more suitable form for increased sustained sea speed.

Modest returns for this project would be realized in the financial return for the scrap, and the savings made by elimination of the maintenance cost for the scrapped vessel.

II. PROCEDURE

In view of the fact that this is a practical and progressive thesis, in that result follows upon result, and not an investigation of any one specific theory, the procedure will list only the investigations made in sequential order and give briefly the method used for each investigation. The degree of thoroughness was chosen commensurate with the importance on the final overall result.

Tentative machinery arrangements were made for doubling the power by duplication of machinery. An attempt was made to maintain single screw propulsion and to keep the increase in space requirements to a minimum. Changes were viewed with respect to keeping the cost as small as possible. Any new equipment needed was tentatively designed using established procedures and rules.

To determine the desired increase in length the sectional area curve of the existing Liberty Ships was stretched out from station three (3) forward, as if by pulling the nose to four predetermined lengths to ascertain the decrease in resistance. The resistance of these modified forms was calculated using Taylor's Standard Series. The goal of a sustained sea speed of fifteen (15) knots was established and strived for. From this investigation an increase in length was decided upon for increased speed and a more suitable bow form for maintaining this speed under service conditions was selected.

From this information an actual set of lines was

prepared for the new bow by fairing into the existing lines at station three (3).

Once the form of the new bow was determined, the effect on the overall ship's characteristics, i.e. displacement and other curves, was calculated. This calculation was made on a change basis; deductions for the old bow and additions for the new bow.

Bulkhead spacing was checked by drawing a new floodable length curve using Webster's method. Changes in capacities of cargo and fuel oil were made from curves of molded volume with assumed deductions for interference and structure. Range was checked using existing fuel rate information. Other investigations were made for weight changes, and strength.

To obtain an approximate overall evaluation for this proposal, letters describing this plan were sent to four leading shipbuilding yards requesting a rough cost estimate.

III. RESULTS

Figs. 1 and 2 show the existing machinery arrangement. Figs. 3 and 4 show the final machinery arrangement as a result of this proposal. Comparison of Figs. 1 and 2 with Figs. 3 and 4 should clearly illustrate the changes made. The salient features of all changes are as follows:

1. Forward engine room bulkhead moved forward from frame 88 to frame 81.

2. Two additional boilers installed between frames 88 and 82 without any changes to the existing fuel oil system piping.

3. Two forced draft fans placed in the overhead behind the boilers on opposite sides with each one to supply an athwartships row of two boilers. The fans were located at: frame 92 Port and frame 82 Starboard.

4. Changes in forced draft ducting and boiler uptakes are illustrated in Figs. 9 and 10.

5. Two main engines, ^{each} mounted ^{6'6"} ~~13 feet~~ off the centerline between frames 97 and 107 with the Port engine HP cylinder forward, and the Starboard engine HP cylinder aft. The engine driven auxiliaries and main condenser were maintained in the same position relative to each main engine so that no modifications are needed.

6. New reduction gear for engine speed of 76 rpm to propeller shaft speed of 85 rpm mounted between frames 108 and 110. A plan view of the gears is illustrated in Fig. 6. Changes to deep tank #3 for installation of reduction gears

and clearances for gear repairs are illustrated in Figs. 3 and 7. New mechanical type flexible couplings are to be installed in spaces indicated in Fig. 6.

7. Two Main Circulating Pumps, 3 Fuel Oil Service Pumps, 4 Main Feed Pumps, and 4 Auxiliary Generators placed in locations indicated in Figs. 3 and 4. Locations of all other auxiliary machinery are also illustrated; however there is no change in the number of each required.

8. New line shafting of 15.25" diameter and new tail shafting of 17" diameter to be installed in the present shaft line.

9. New stern tube is illustrated in Fig. 11.

10. New propeller of 18' diameter.

11. Lines for new bow are illustrated in Fig. 12. For these lines the half angle of entrance of the 27' waterline is 16° . The bow has a 20° raked stem with 10' radius and 53' 7" of cut up.

12. Displacement and other curves for existing ship and for conversion are illustrated in Fig. 14. For these curves whenever the midship station is used for reference this point was maintained at the original midship station.

1. The first of the two main parts of the work is devoted to a general survey of the history of the subject. It begins with a brief account of the early attempts to explain the phenomena of light, and then proceeds to a more detailed consideration of the various theories which have been proposed from time to time. The author shows how the different theories have been modified and improved upon, and how they have finally led to the establishment of the modern theory of light.

2. The second part of the work is devoted to a more detailed consideration of the various phenomena of light. It begins with a chapter on the propagation of light, and then proceeds to chapters on reflection, refraction, diffraction, interference, and polarization. Each of these chapters contains a detailed account of the various experiments which have been performed to illustrate the phenomena, and a discussion of the various theories which have been proposed to explain them.

3. The third part of the work is devoted to a consideration of the various applications of the theory of light. It begins with a chapter on the theory of vision, and then proceeds to chapters on the theory of color, the theory of the rainbow, and the theory of the spectrum. Each of these chapters contains a detailed account of the various phenomena which are observed, and a discussion of the various theories which have been proposed to explain them.

4. The fourth part of the work is devoted to a consideration of the various applications of the theory of light to the various branches of science. It begins with a chapter on the theory of the microscope, and then proceeds to chapters on the theory of the telescope, the theory of the camera, and the theory of the spectrometer. Each of these chapters contains a detailed account of the various instruments which are used, and a discussion of the various theories which have been proposed to explain the phenomena which are observed.

5. The fifth part of the work is devoted to a consideration of the various applications of the theory of light to the various branches of industry. It begins with a chapter on the theory of the lamp, and then proceeds to chapters on the theory of the candle, the theory of the gas lamp, and the theory of the electric lamp. Each of these chapters contains a detailed account of the various instruments which are used, and a discussion of the various theories which have been proposed to explain the phenomena which are observed.

13. *Coefficients of the new hull form at 27.15 ft. waterline are:
- | | | |
|--------------|-----------------|------------------|
| $C_p = .741$ | $C_{pe} = .710$ | $L_e = 43.2\%$ |
| $C_b = .730$ | $C_{pr} = .715$ | $L_{mb} = 9.5\%$ |
| $C_w = .820$ | | $L_r = 47.3\%$ |
- $\Delta = 14,175$ tons
- L.C.B. 12.1' forward of existing midship section or
0.1' forward of new midship section.
14. New floodable length curve is illustrated in Fig.15.
15. Profile of the new bow is illustrated in Fig. 13.
16. New light ship displacement = 3868 tons.
17. New fuel oil capacity = 2453 tons.
18. New grain cubic = 550,142 cu. ft., new bale cubic = 494,446 cu. ft.
19. Calculated EHP bare/ SHP at engine = .78
20. Final curves for EHP bare and SHP at engine versus speed for conversion at a draft of 27.15' are illustrated in Fig. 19.
21. Range = 17,500 miles at 15.3 knots, or 48 days.

* Definition of coefficients, Reference 5, p.8,9,10

THE HISTORY OF THE UNITED STATES

1776	1777	1778
1779	1780	1781
1782	1783	1784

THE HISTORY OF THE UNITED STATES

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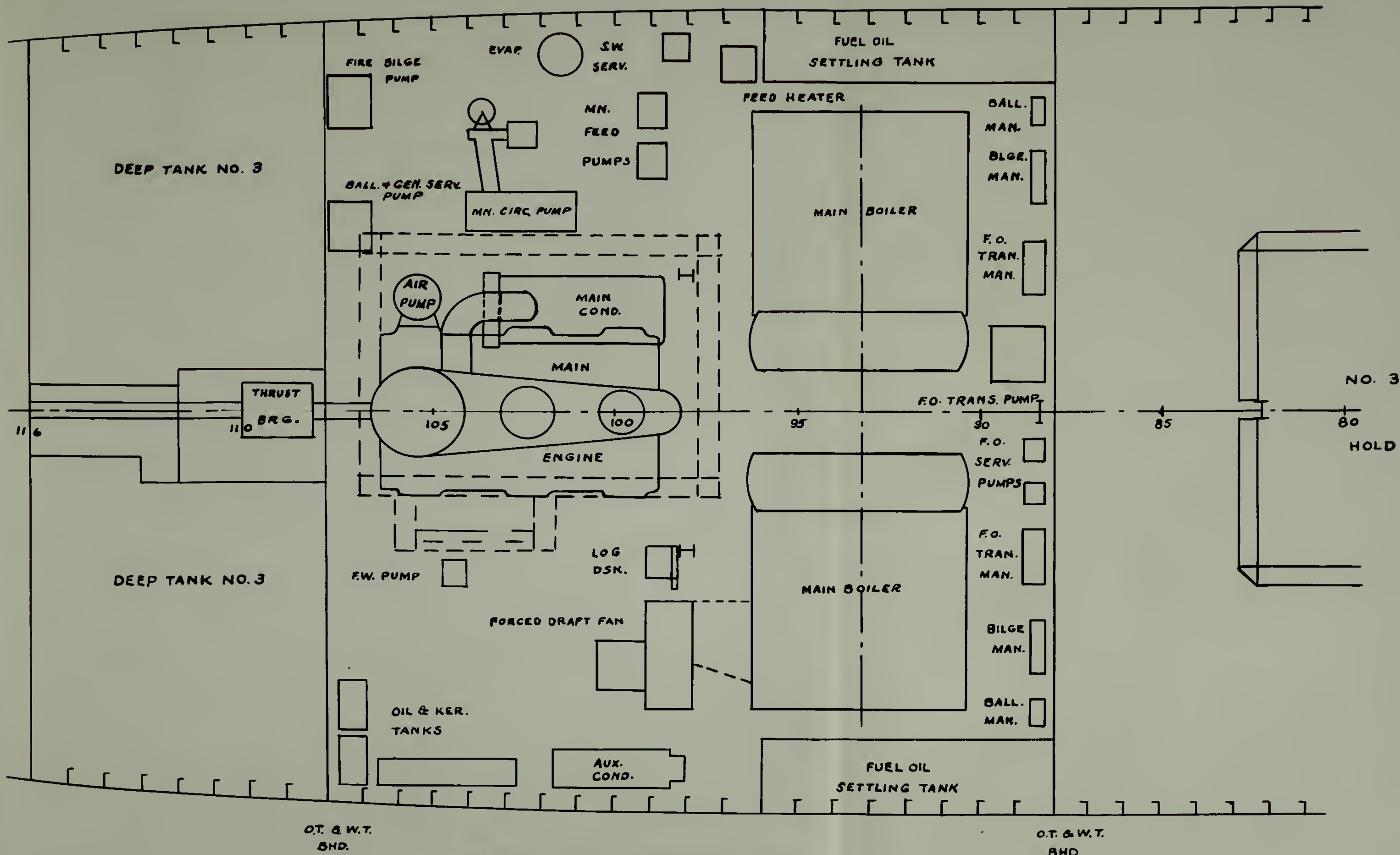
THE HISTORY OF THE UNITED STATES

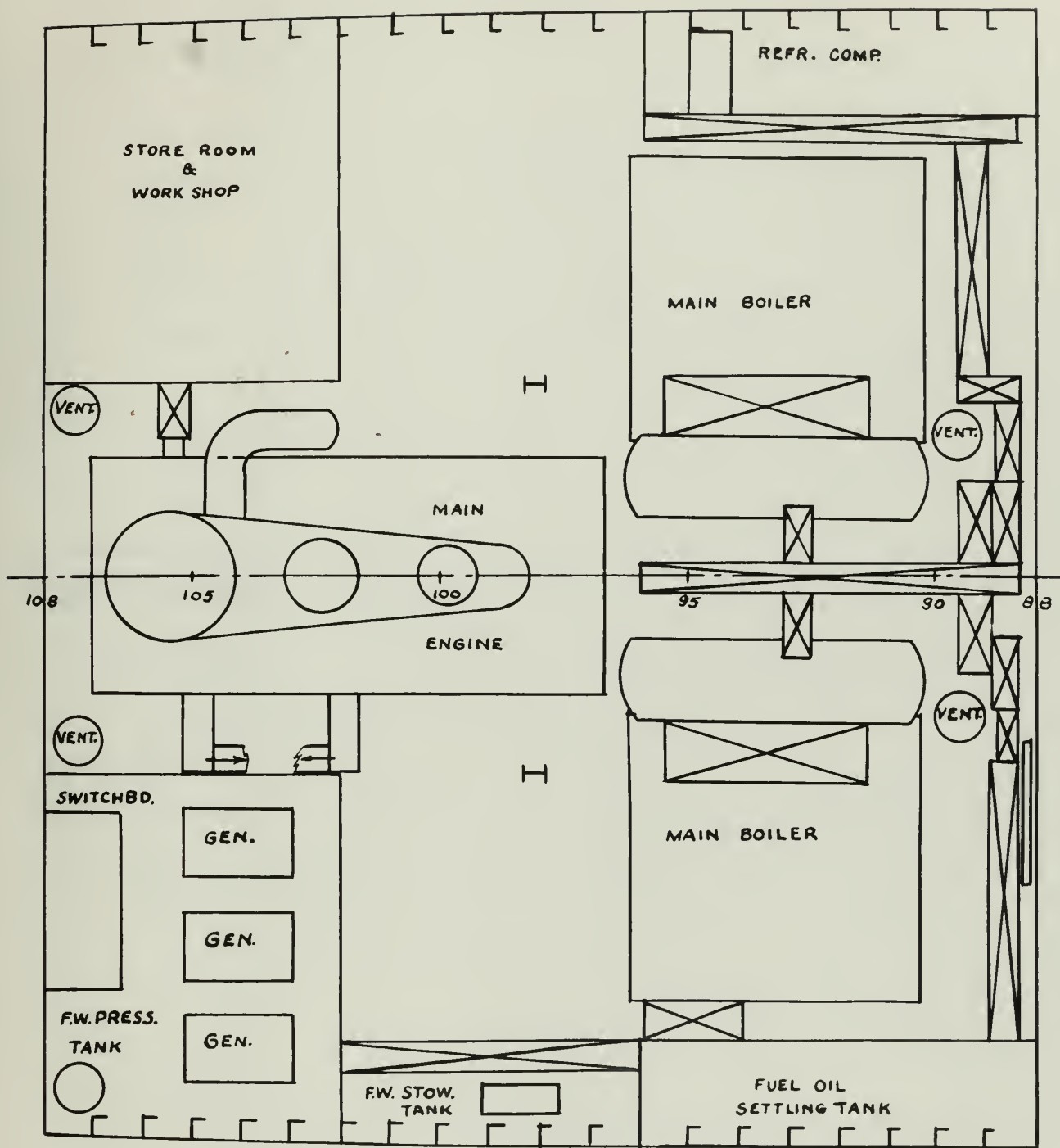
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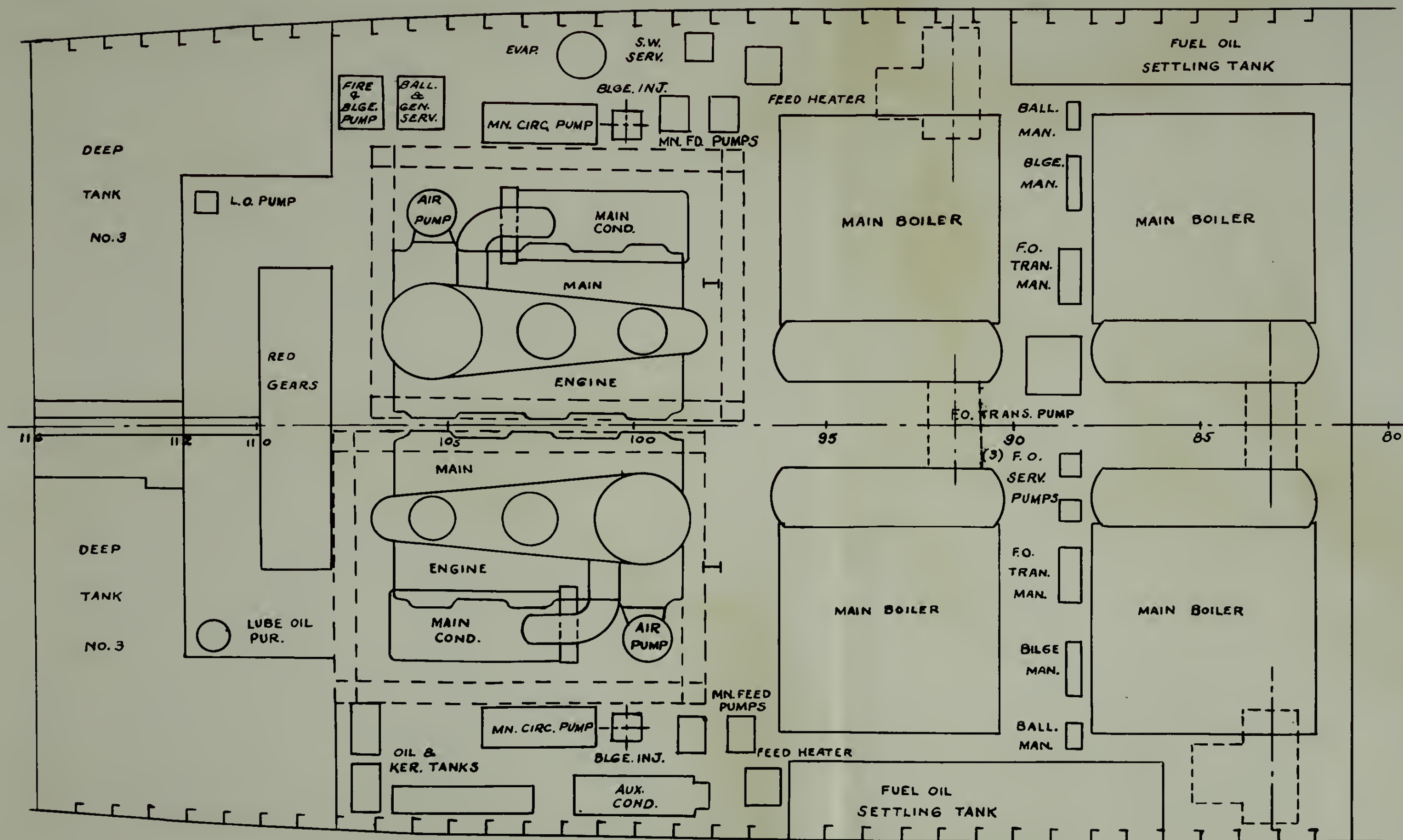


LIBERTY SHIP CONVERSION - FIG. 2

MACHINERY ARRANGEMENT

EXISTING UPPER LEVEL - SCALE $\frac{1}{8}" = 1\text{ FT.}$

W.B.K. 3 APRIL, 1954 C.S.M.

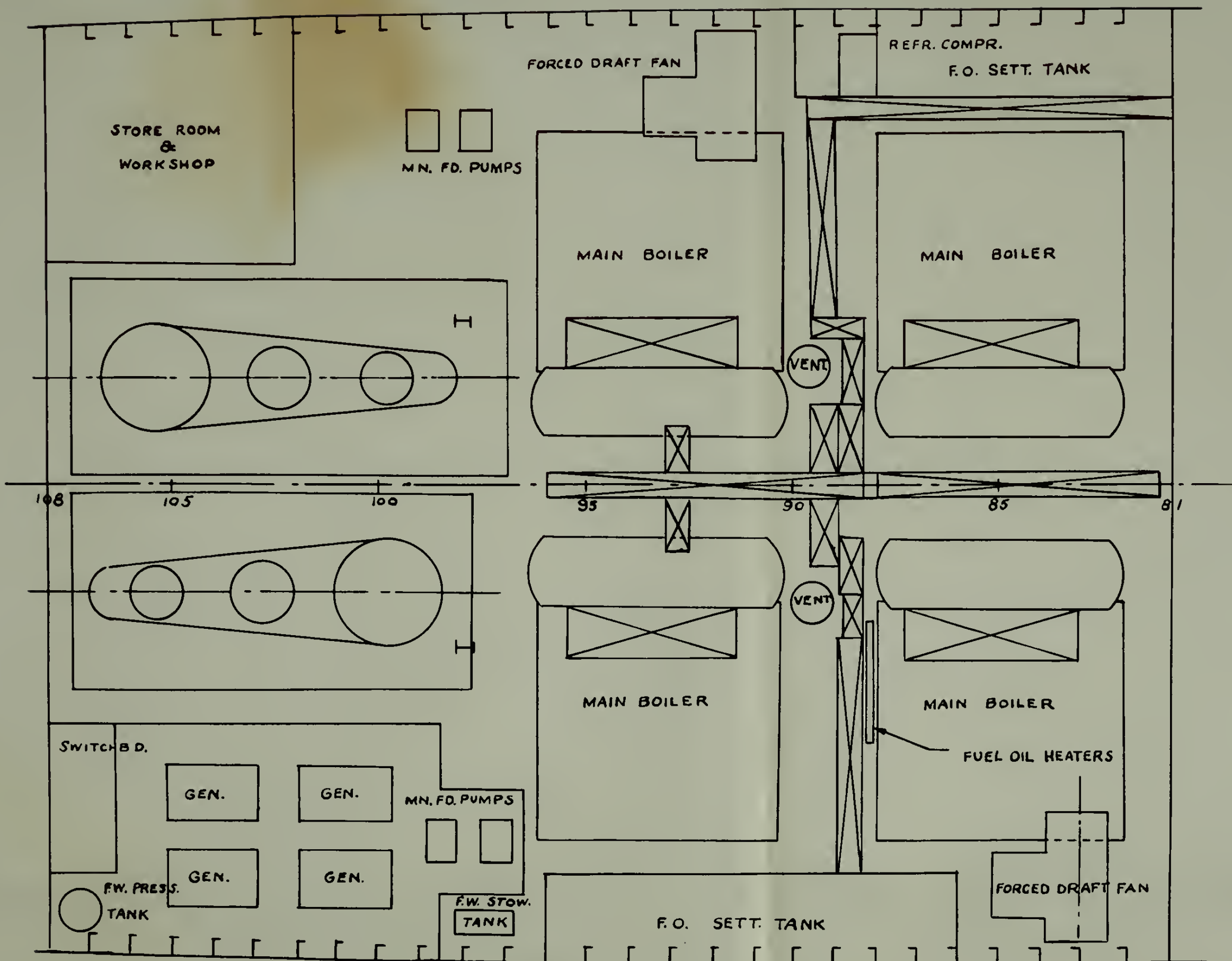


LIBERTY SHIP CONVERSION-FIG. 3

31813. 3 APRIL, 1954 C.S. 72.

MACHINERY ARRANGEMENT LOWER LEVEL

SCALE $\frac{1}{8}$ " = 1 FT.

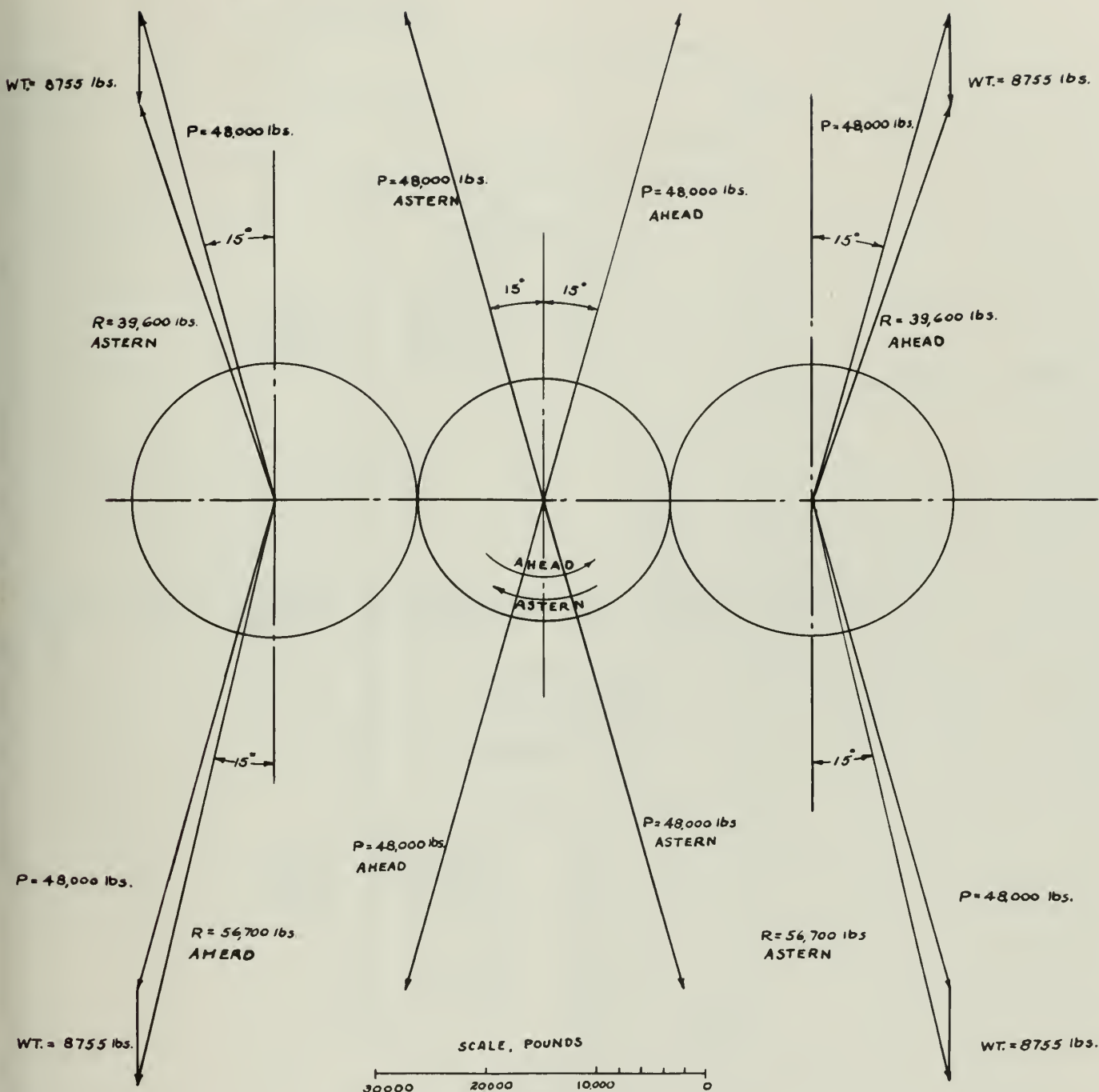


LIBERTY SHIP CONVERSION- FIG. 4

MACHINERY ARRANGEMENT UPPER LEVEL

SCALE $\frac{1}{8}$ " = 1 FT.

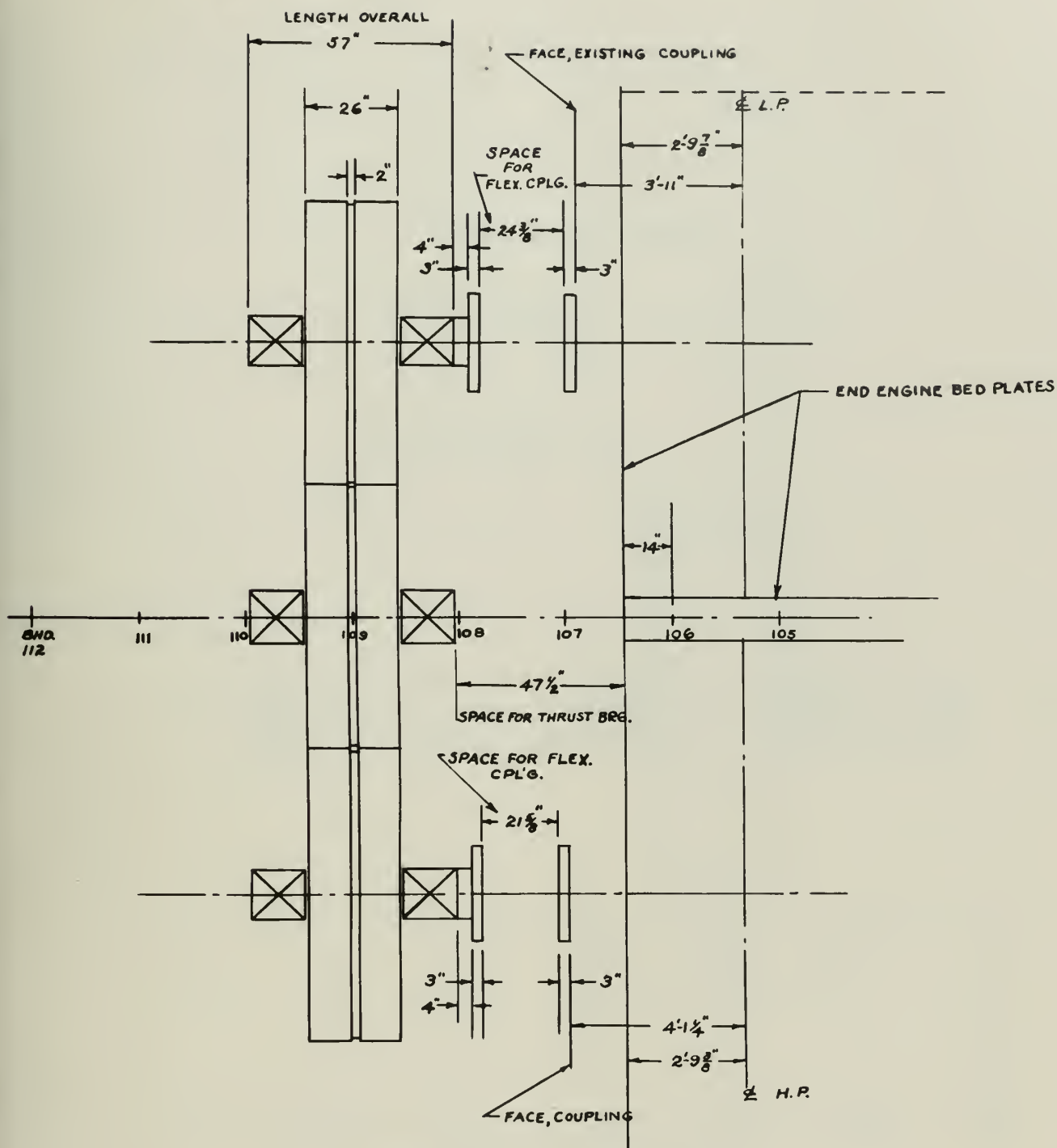
WDB. 3 APRIL, 1954 C.S.M.



LIBERTY SHIP CONVERSION - FIG. 5

GEAR BEARING LOAD DIAGRAM
SCALE AS SHOWN

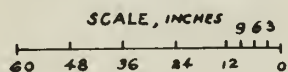
300 3 APRIL, 1954 C.577.



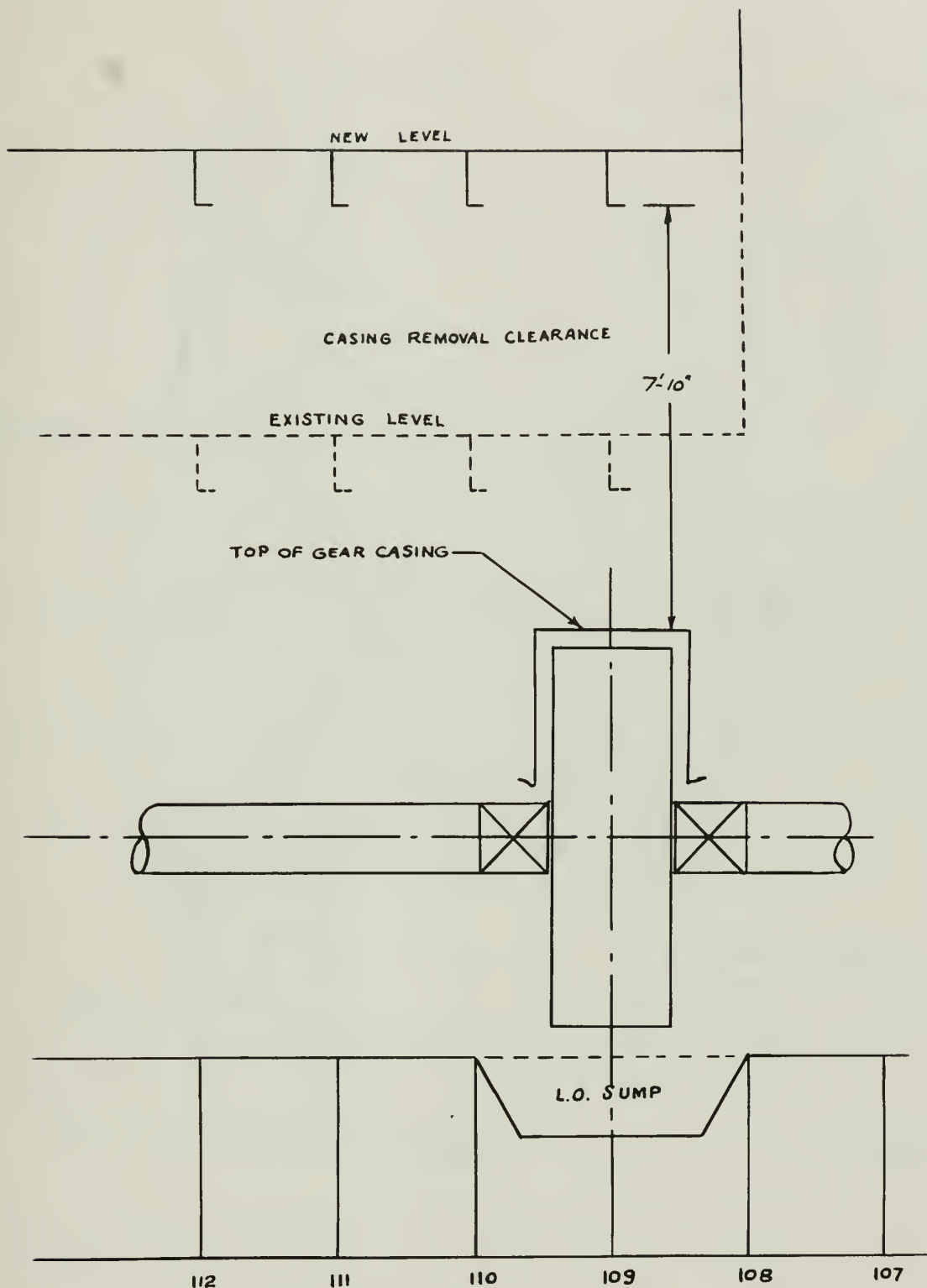
LIBERTY SHIP CONVERSION - FIG. 6

PRELIMINARY EXPANDED LONGITUDINAL

SECTION OF GEARS



72.6 3 APRIL, 1954 C.S.M.



LIBERTY SHIP CONVERSION - FIG. 7

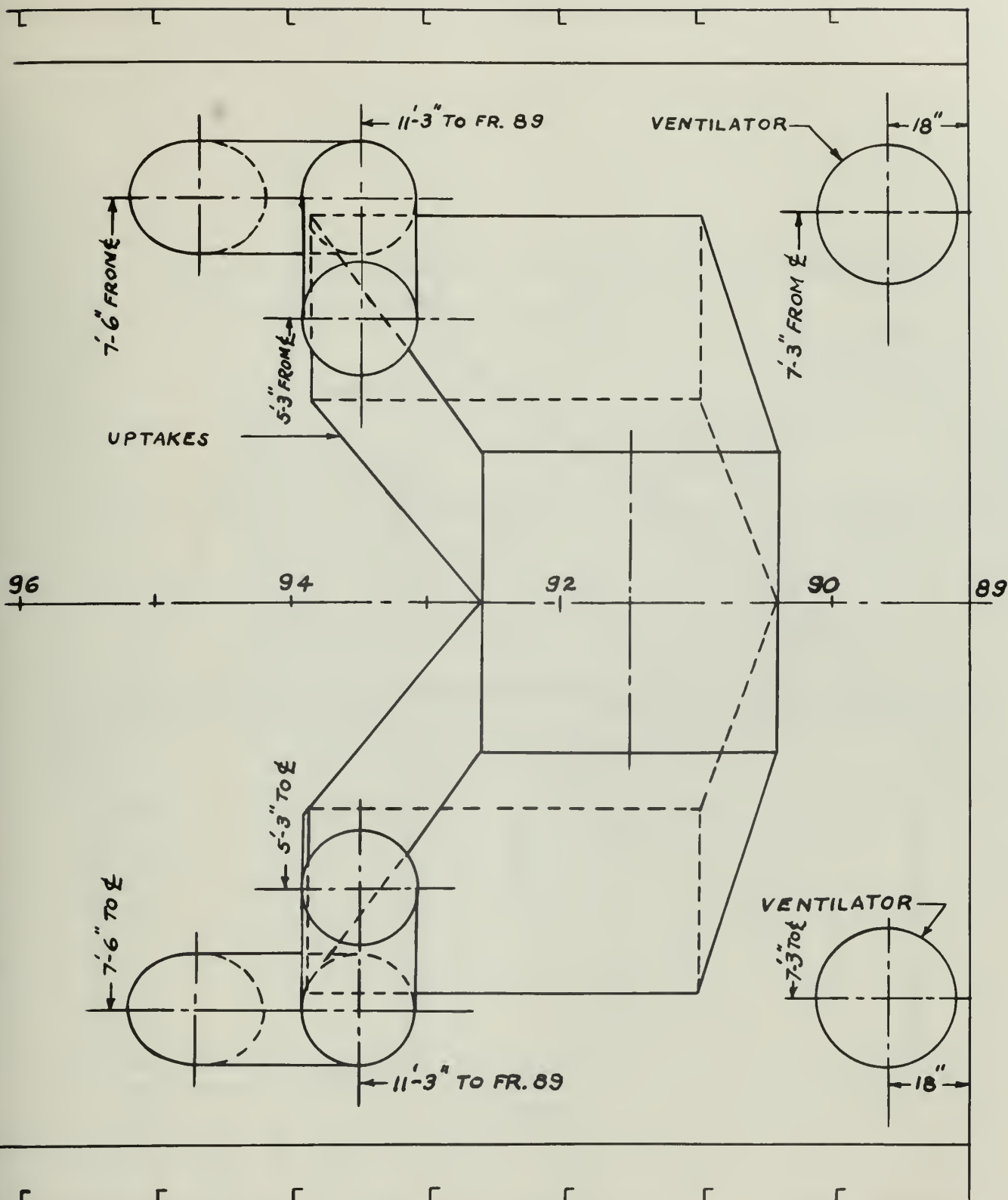
ELEVATION AT $\frac{1}{2}$ OF REDUCTION GEARS

SHOWING NECESSARY CLEARANCE FOR REMOVAL

SCALE $\frac{3}{8}" = 1\text{ FT.}$

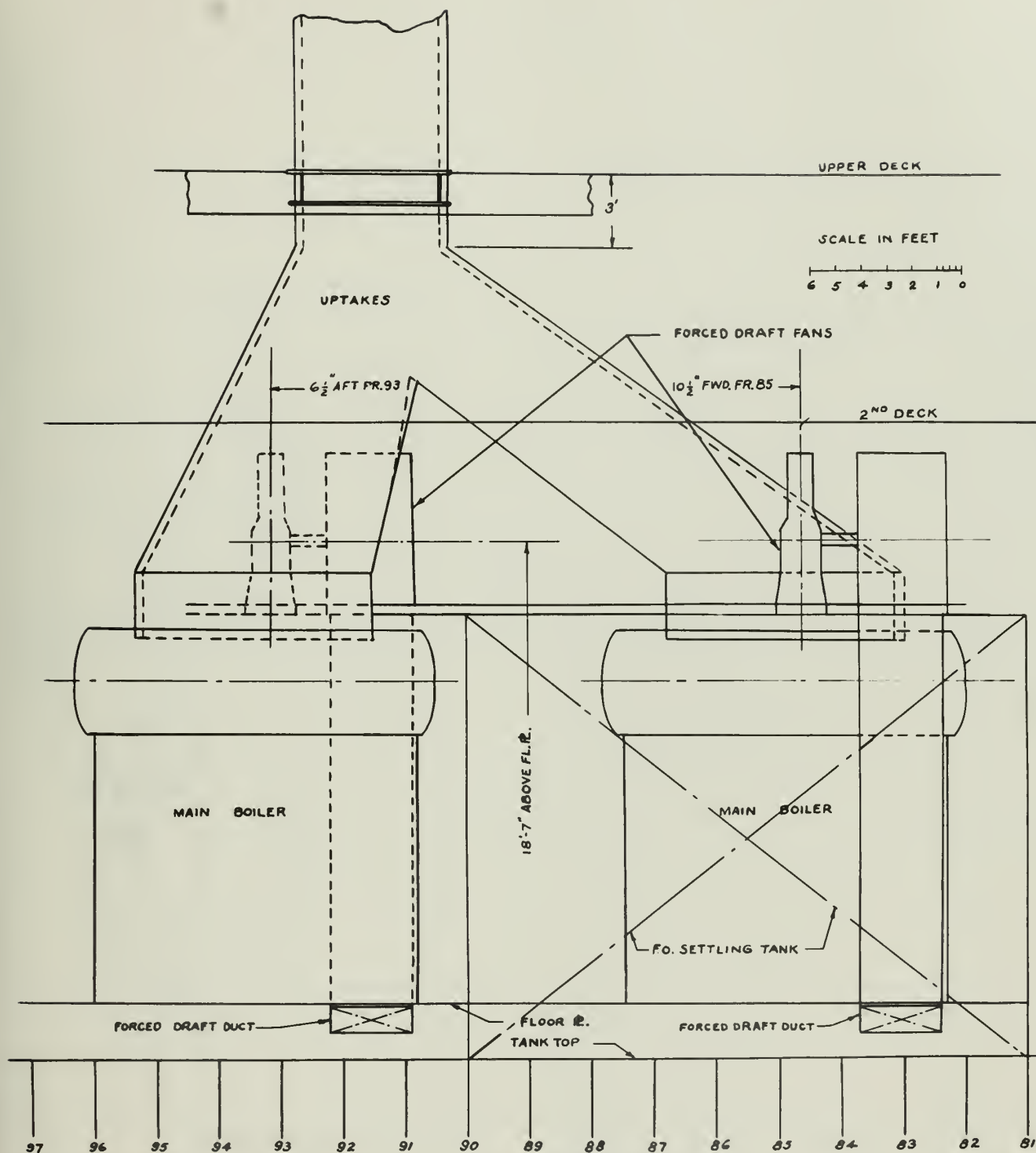
3 APRIL, 1954

CSX

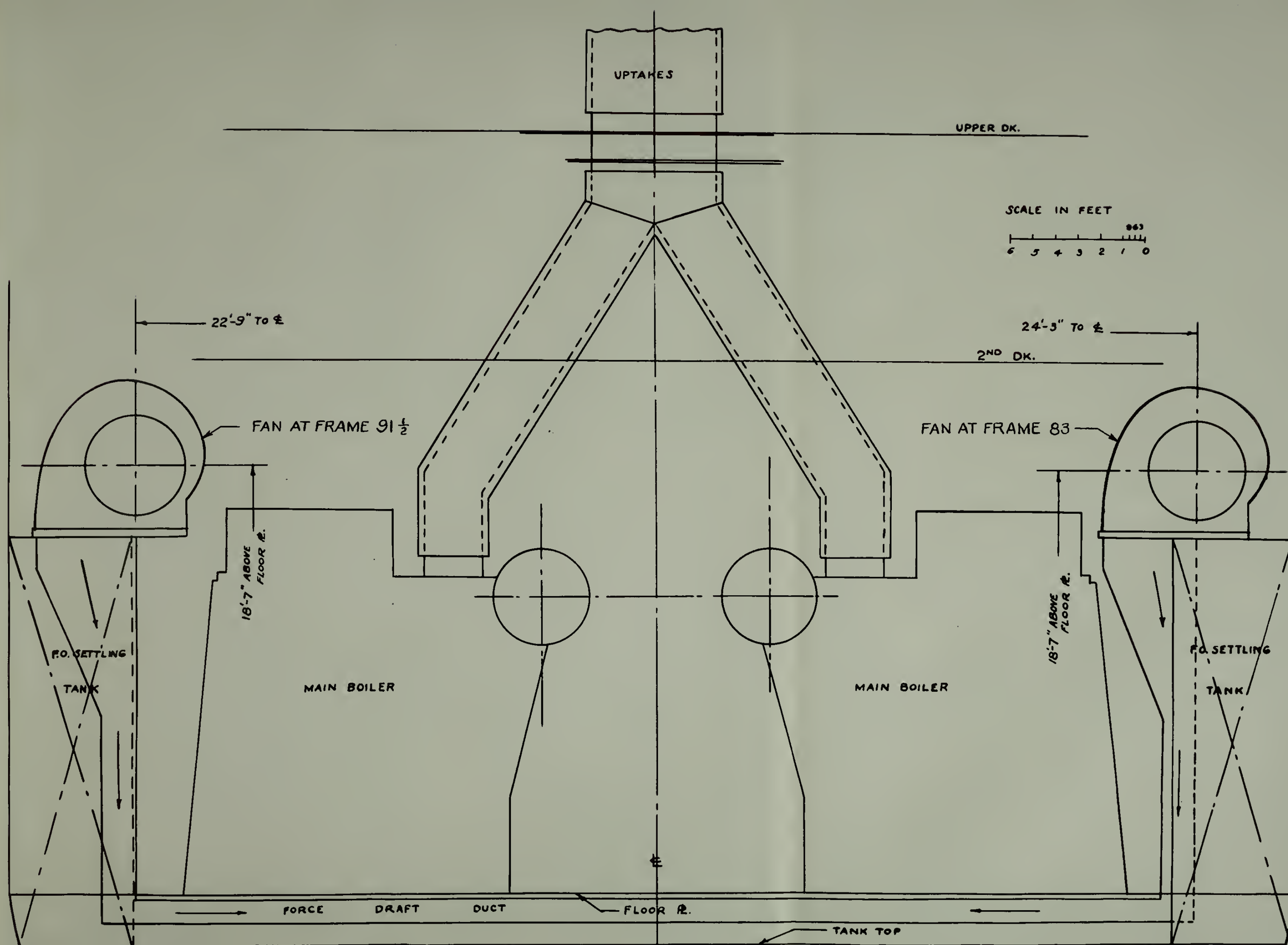


LIBERTY SHIP CONVERSION - FIG. 8
 UPTAKES PLAN VIEW EXISTING - 2ND DECK
 SCALE $\frac{1}{8}" = 1 \text{ FT.}$
 WDB. 3 APRIL, 1954 CSM.





LIBERTY SHIP CONVERSION - FIG. 9
 FORCED DRAFT FAN & DUCT ARRANGEMENT - SIDE ELEVATION
 3 APRIL, 1954 C.S.M.

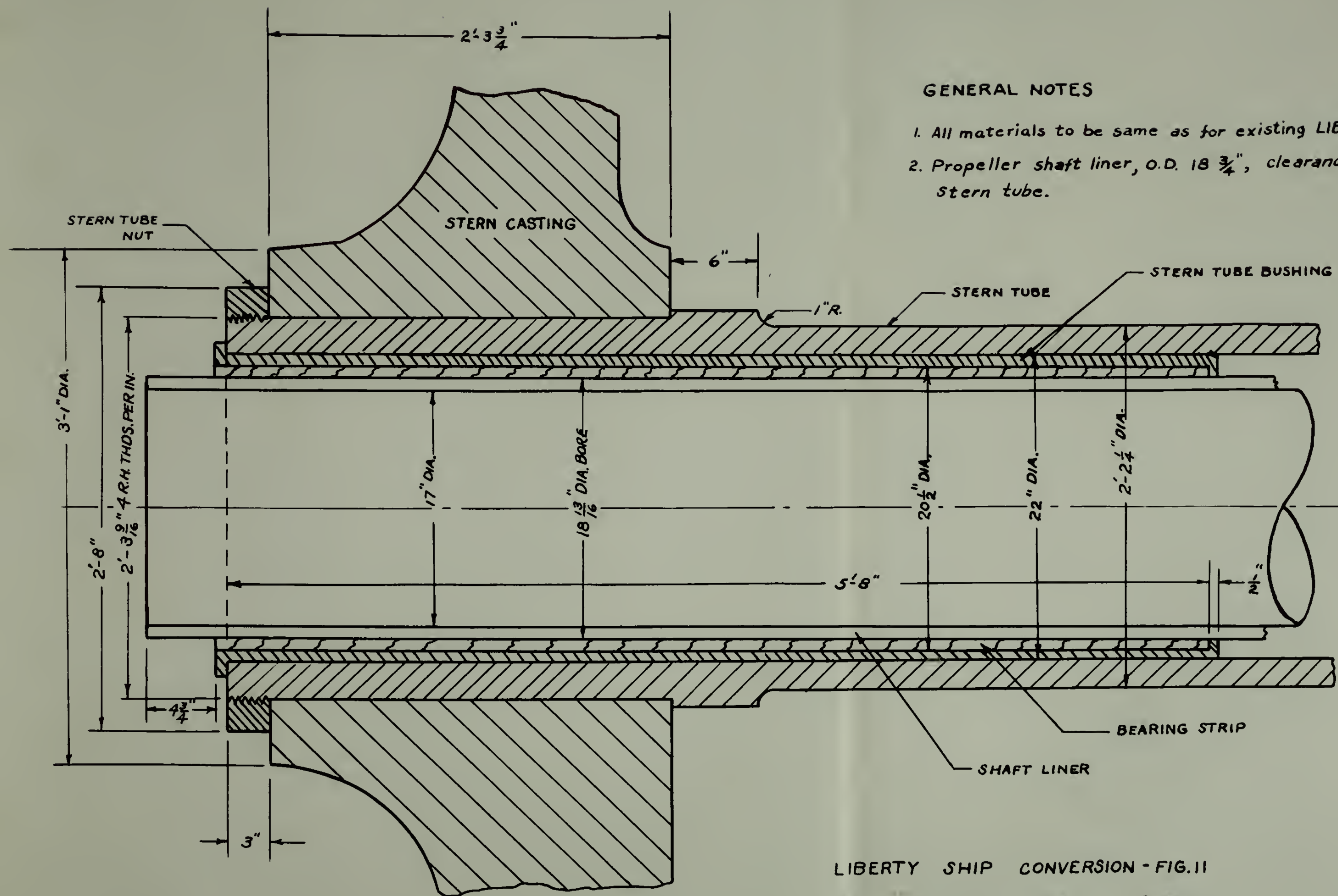


FORCED DRAFT FANS & DUCT ARRGT.

FRAME 96 LOOKING FWD.

LIBERTY SHIP CONVERSION-FIG 10

WDB. 3 APRIL, 1954 C.S.77.



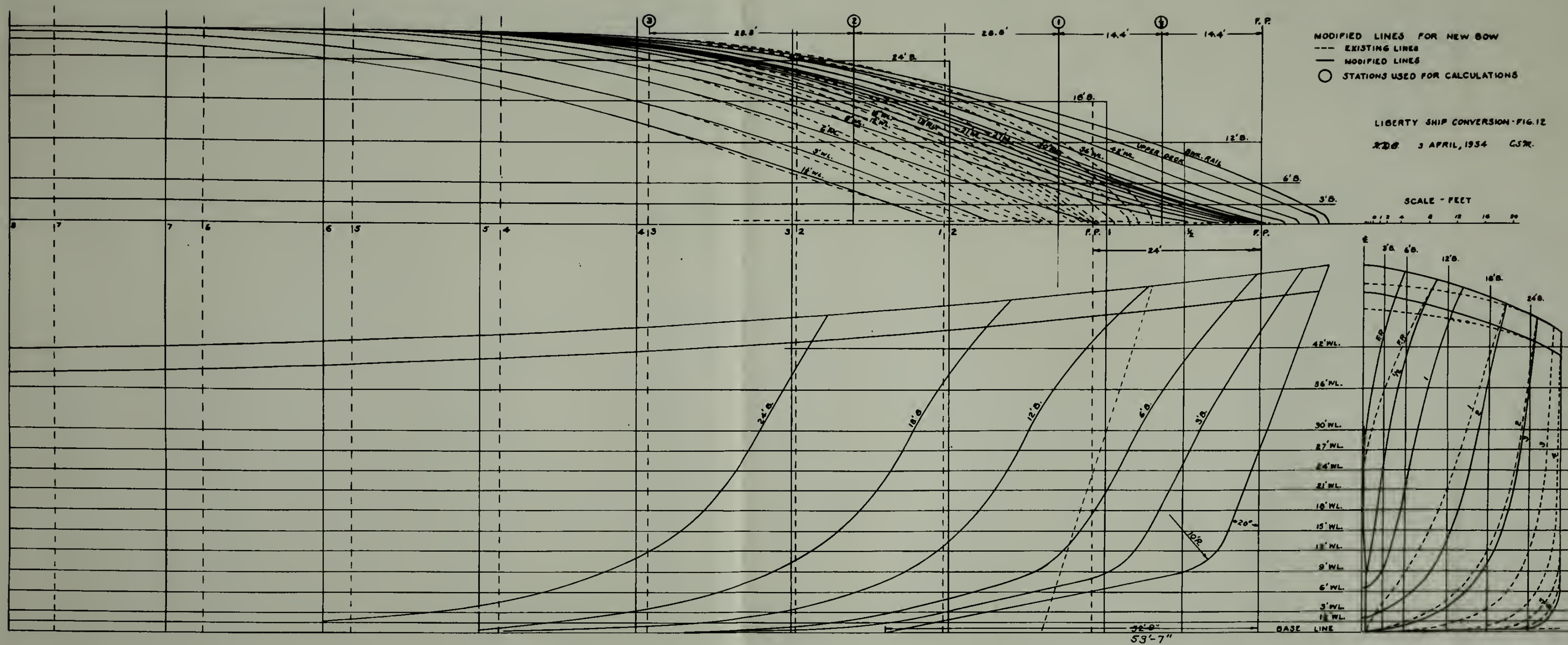
GENERAL NOTES

1. All materials to be same as for existing LIBERTY SHIPS
2. Propeller shaft liner, O.D. 18 3/4", clearance 1/16" in stern tube.

LIBERTY SHIP CONVERSION - FIG. 11

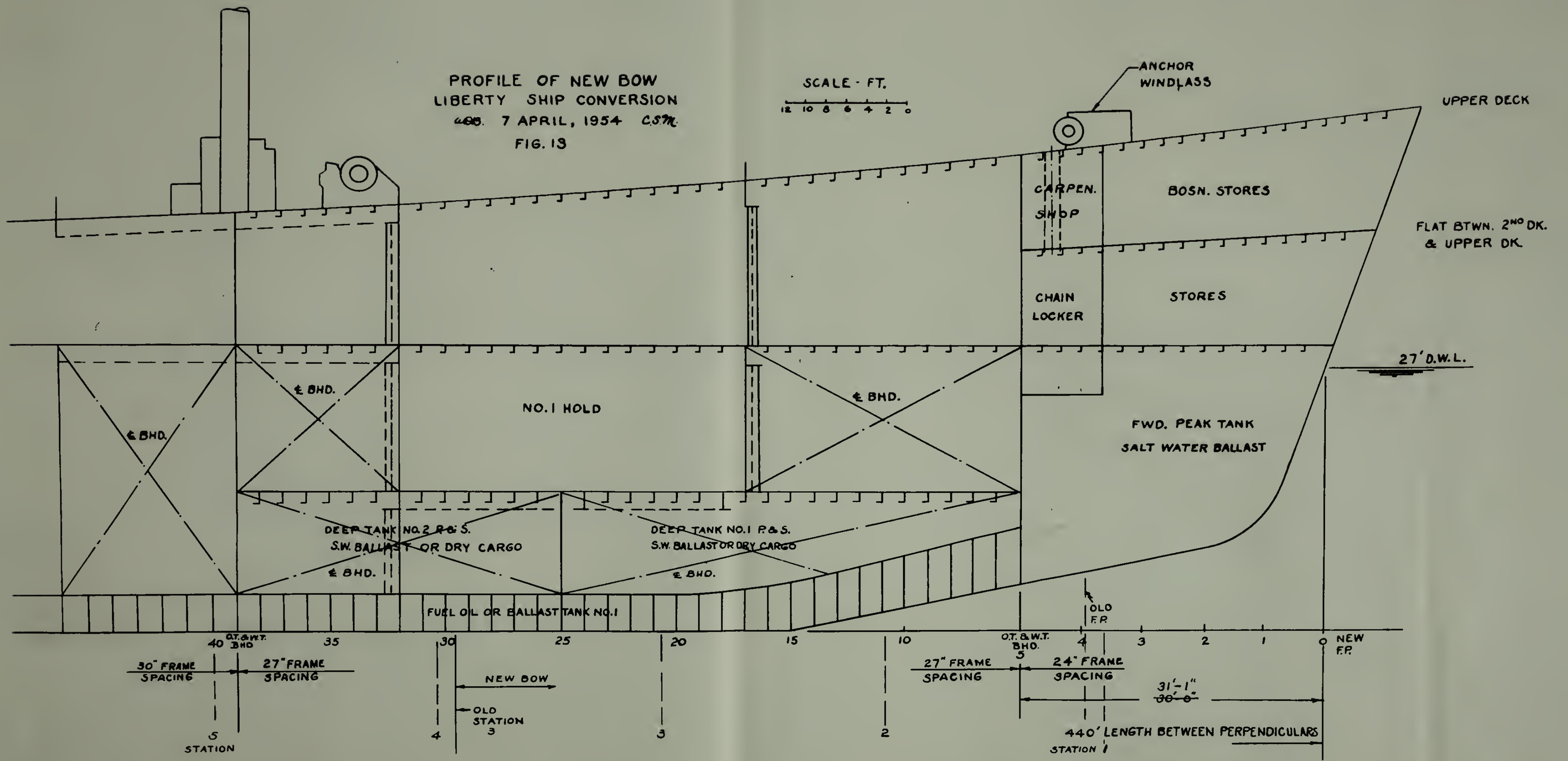
Y.D.B. 3 APRIL, 1954 C.S.72.

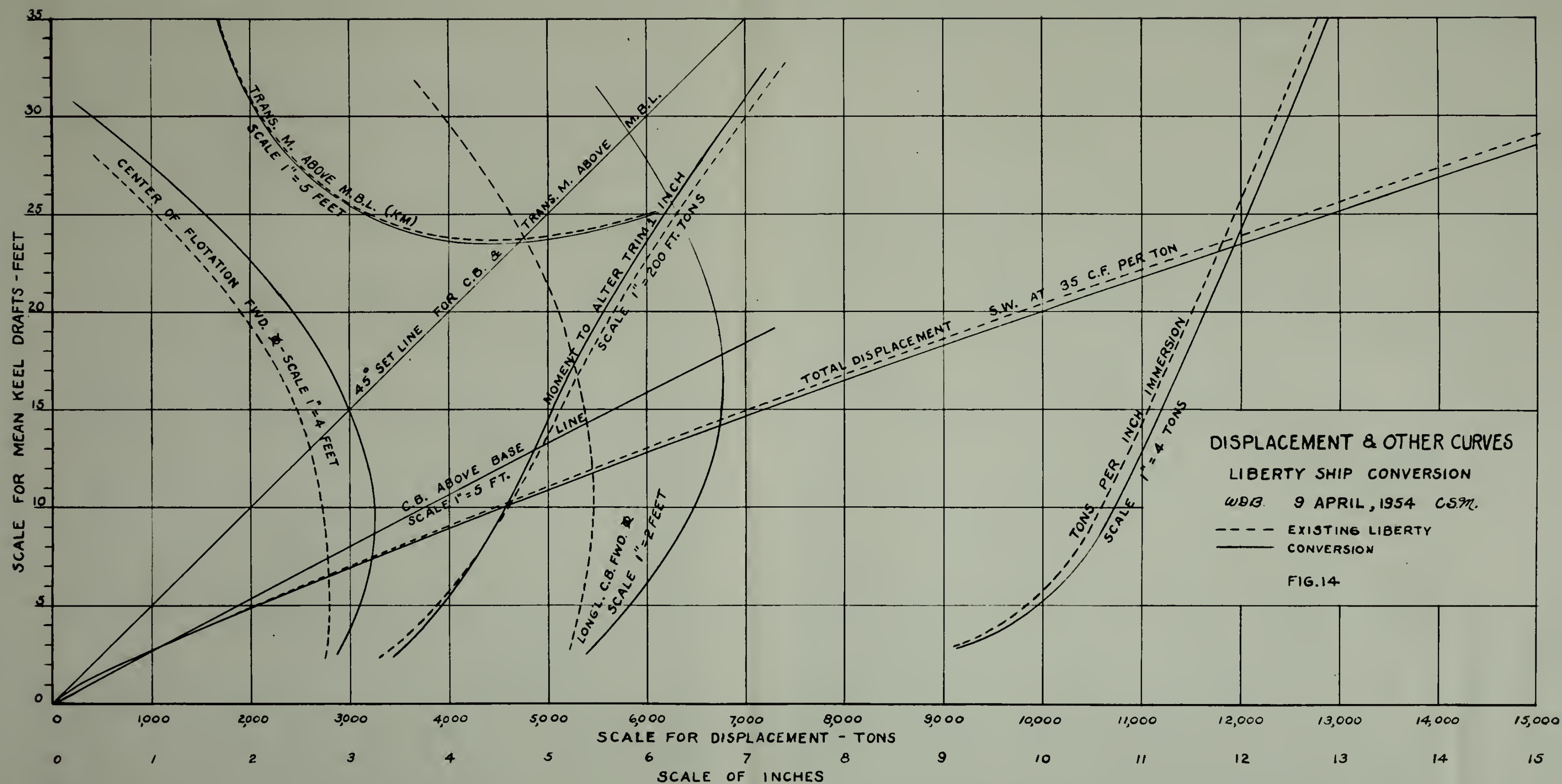
DETAILS AT STERN CASTING



PROFILE OF NEW BOW
LIBERTY SHIP CONVERSION
400. 7 APRIL, 1954 C.S.M.
FIG. 13

SCALE - FT.
12 10 8 6 4 2 0





LIBERTY SHIP CONVERSION

FLOODABILITY CURVES

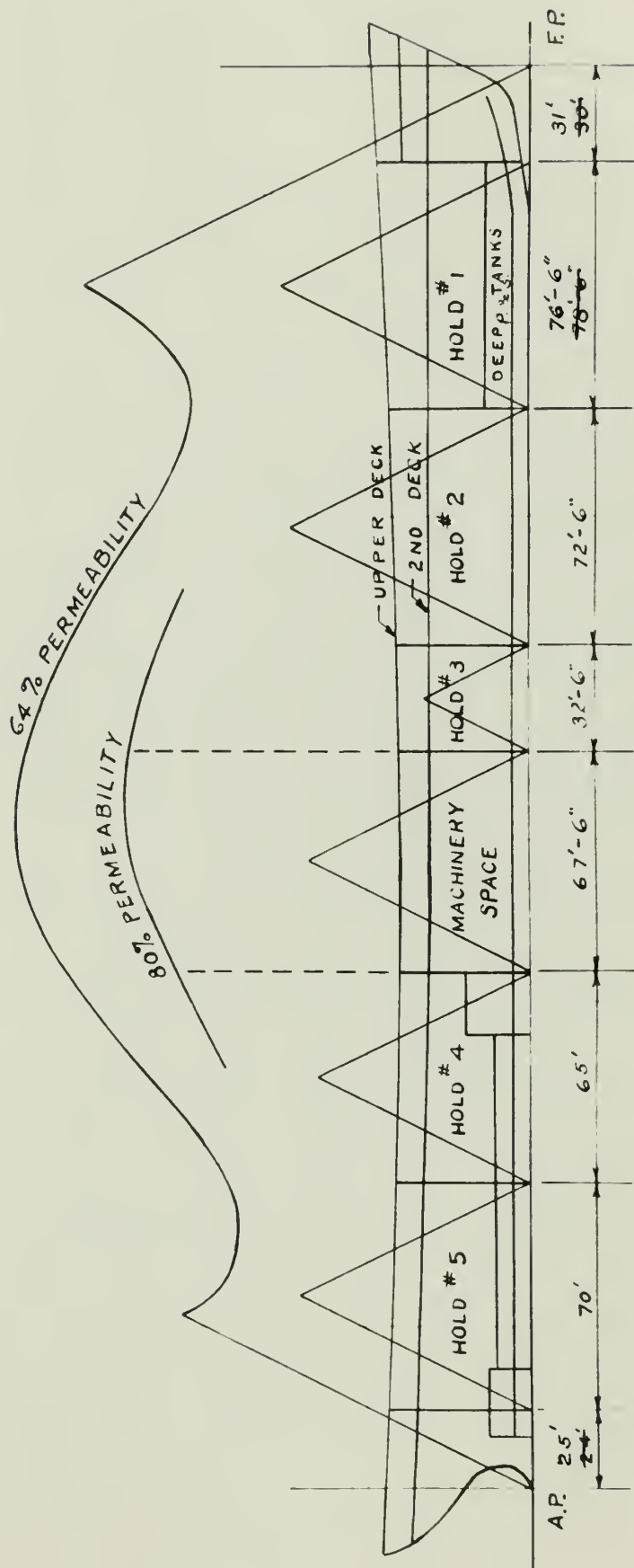
WDB 5 APRIL, 1954 CSZ.

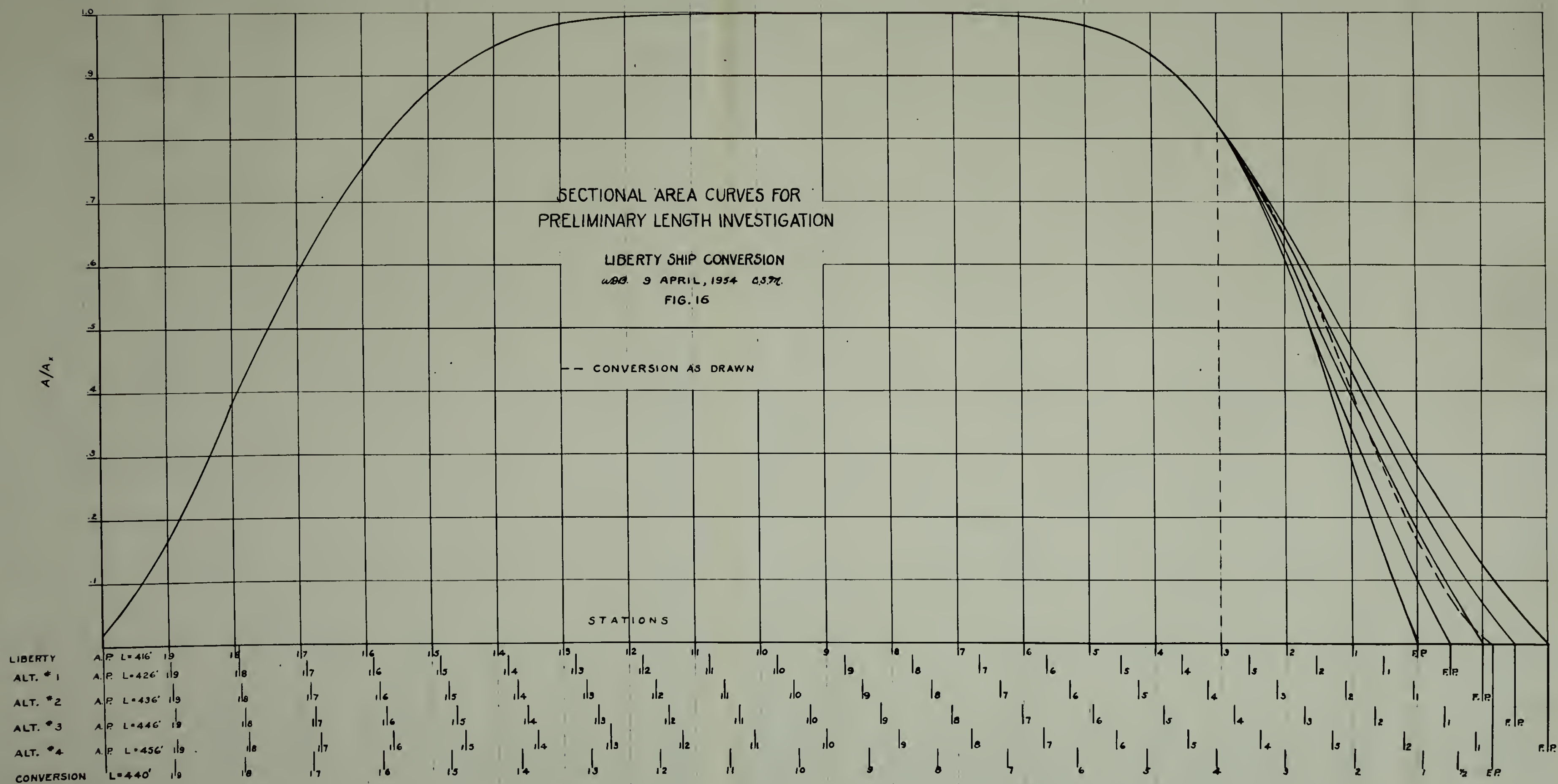
PERMEABILITIES

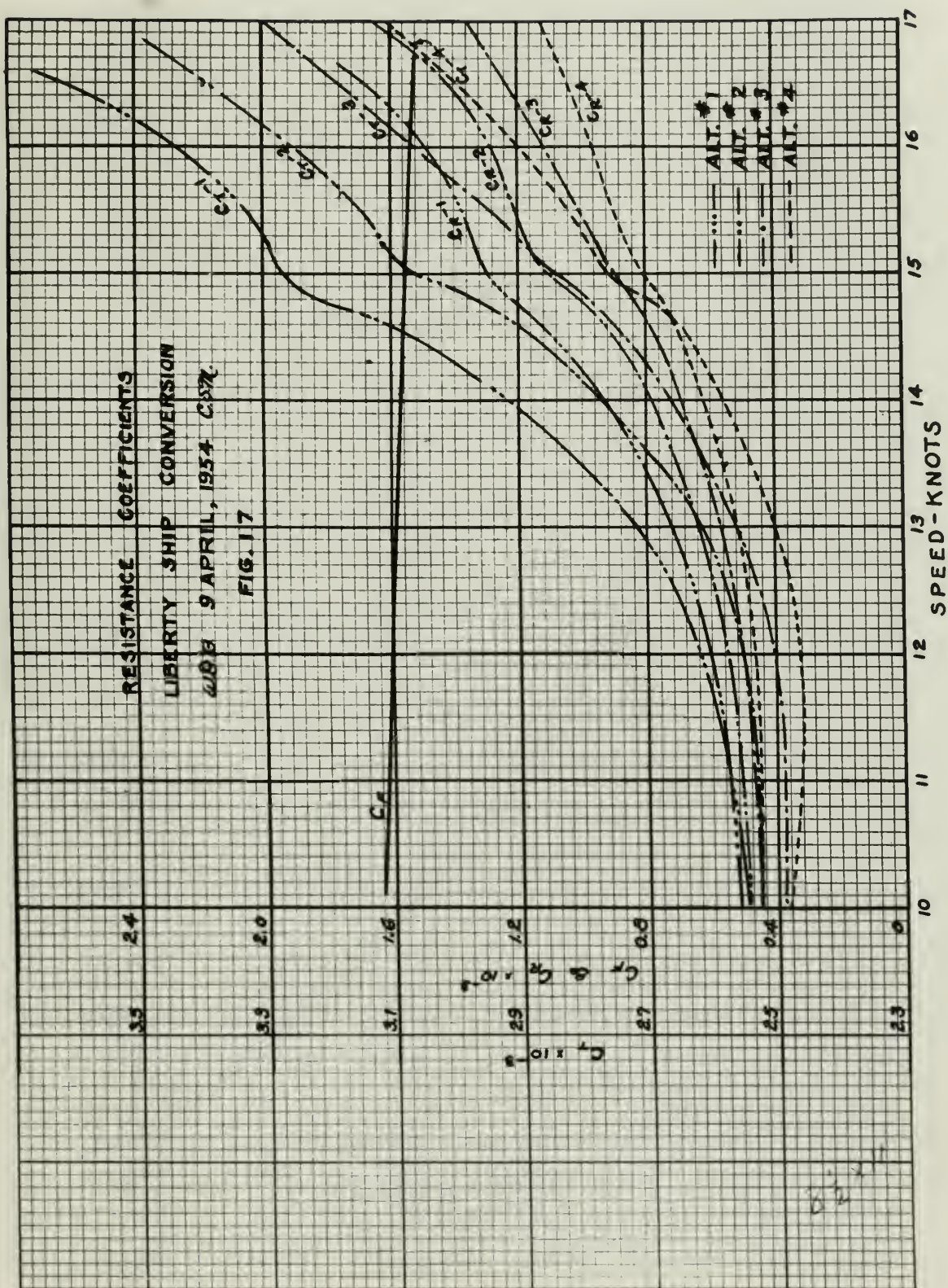
CARGO SPACE 64%

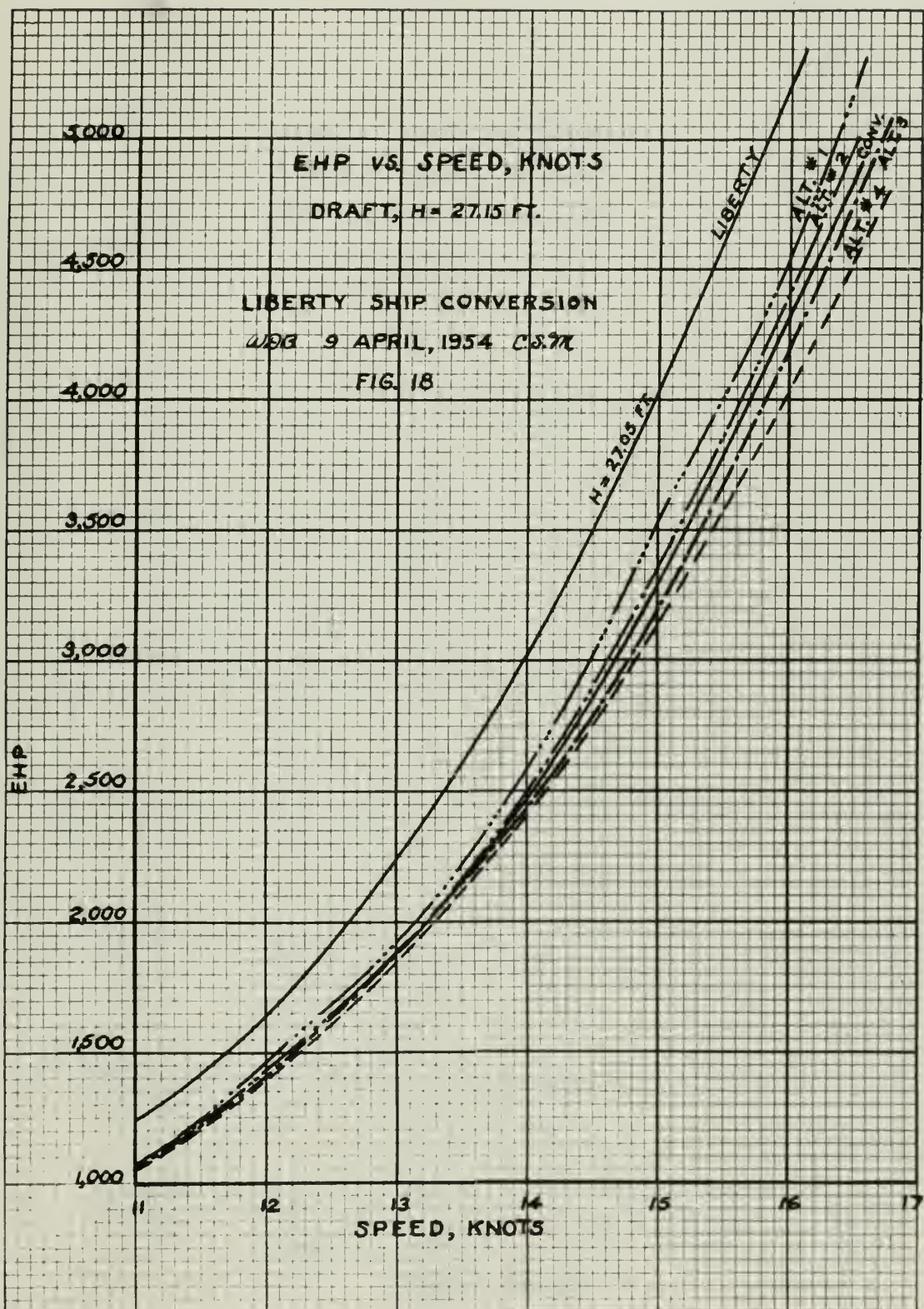
MACHINERY SPACE 80%

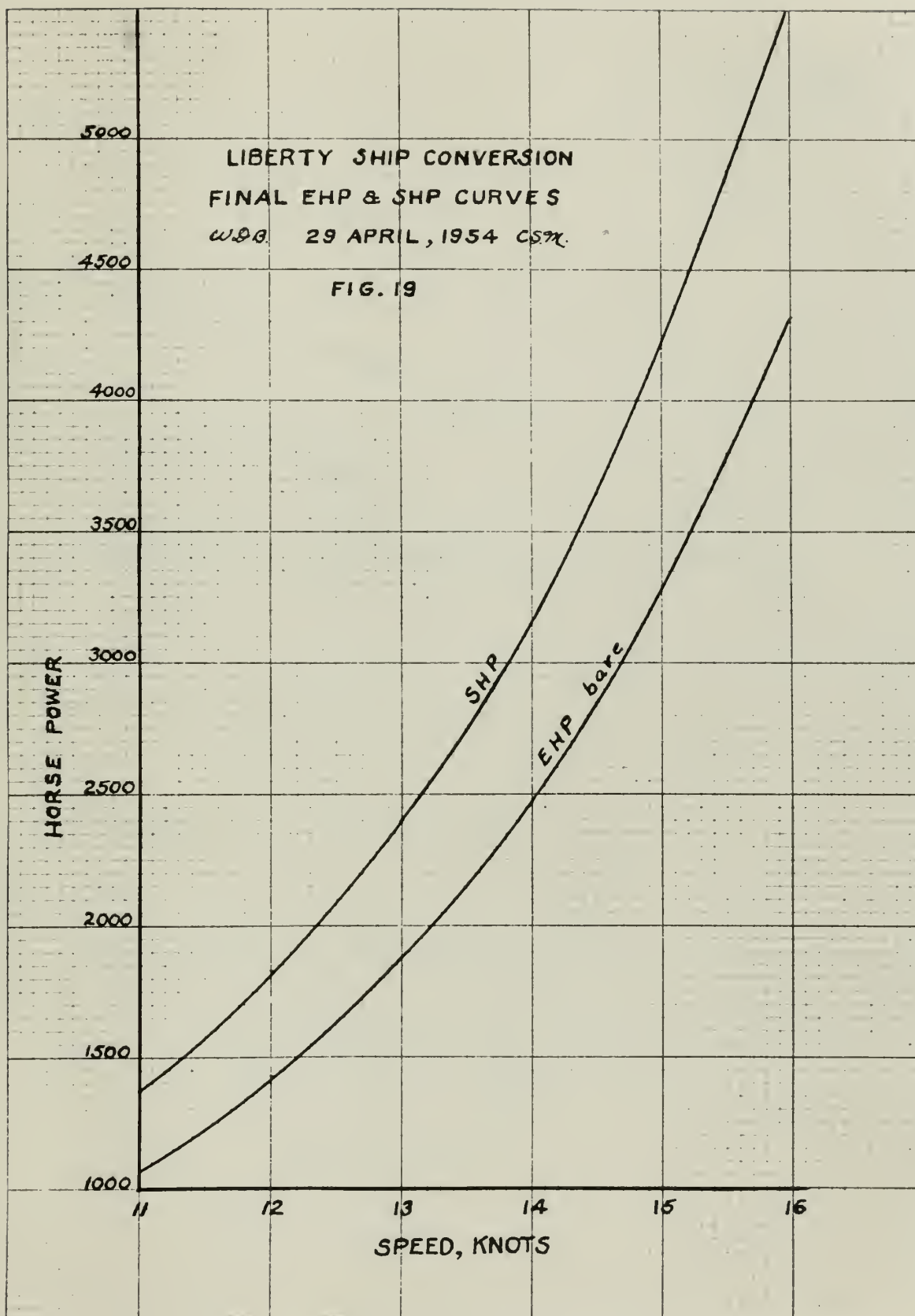
FIG. 15







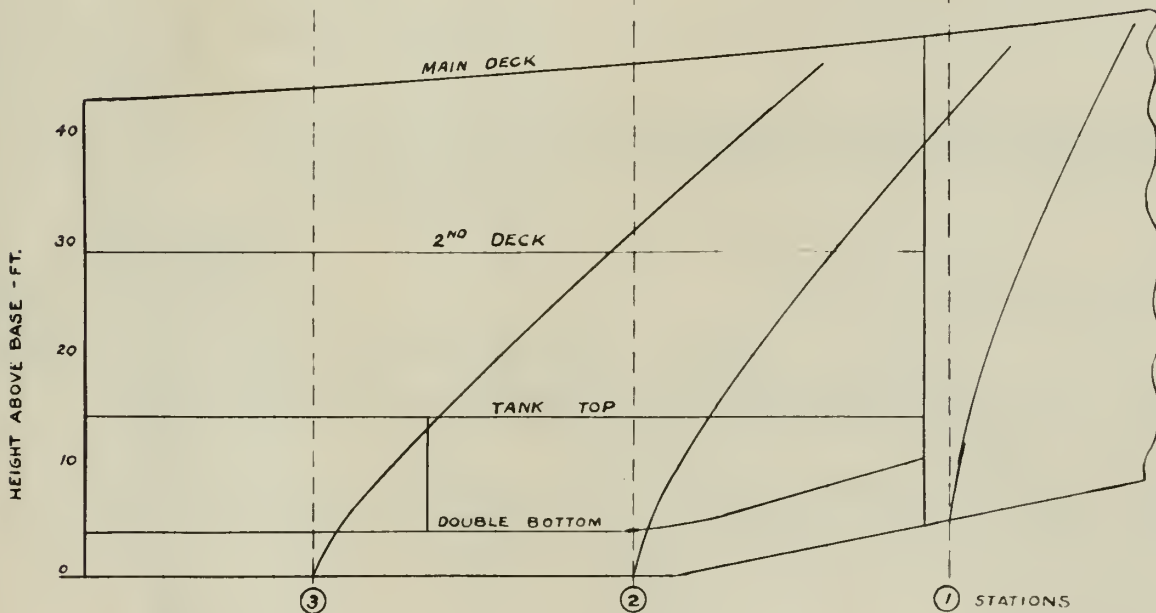
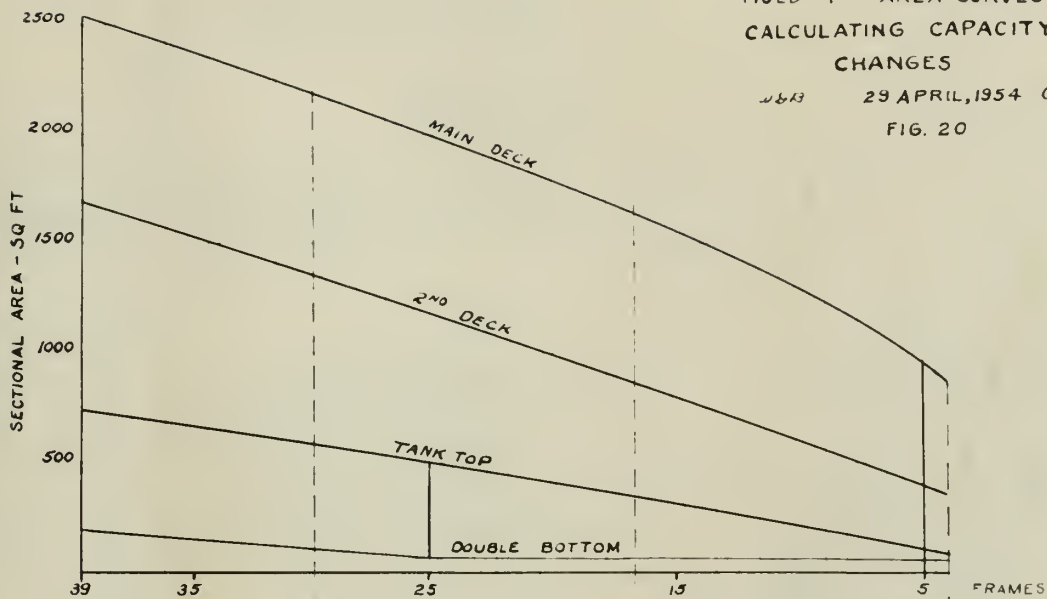




LIBERTY SHIP CONVERSION
HOLD #1 AREA CURVES FOR
CALCULATING CAPACITY
CHANGES

WBA3 29 APRIL, 1954 C597.

FIG. 20



BONJEAN CURVES

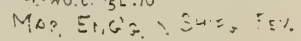


FIG. 21

IV. DISCUSSION OF RESULTS

In this section the subhead numbers will correspond to the topics as listed in the RESULTS.

1. This result is based on many trial and error arrangements of the basic machinery. The final result was chosen for its compactness in that it produced the smallest increase in engineroom size. Conversely, this resulted in the smallest decrease in the volume of Hold #3. In effect, this bulkhead movement was needed only for the installation of the two additional boilers.

2. The two existing boilers are left unchanged, as any movement would necessitate additional cost. The location of the additional boilers was chosen for the purpose of keeping fuel system piping, manifolds, and pumps in their present location, again requiring no changes. The only additional fuel oil piping required is necessary for firing the added boilers. This location also provides necessary clearances.

3. Since two extra boilers are required for doubling the power, two forced draft fans are needed, each one to supply two boilers as in the existing plant. To keep the working space at a maximum on the lower level, the forced draft fans were placed on a level with the top of the fuel oil settling tanks. In this manner the ducts were placed in back of the boilers near the skin of the ship. Each forced draft fan supplies two boilers in athwartship position. By arranging the fans in this way the maximum amount of fuel oil settling tank volume can be utilized.

4. The new forced draft ducting supplies each of the two athwartships boilers from below, and encounters no interference from existing piping systems. Running the ducting in this manner was the only way that both objectives could be met and still keep the length of ducting small.

The uptakes for the existing boilers are not changed. The uptakes for the additional boilers join the existing uptakes at the base of the stack. The stack does not need to be enlarged, as shown in APPENDIX K.

5. The main engines are located in the same longitudinal position as on the existing Liberty Ships, between frames 97 and 107. Keeping the engines in this location has two advantages; existing hull reinforcements may be utilized for strength and also the length of the engine room can be kept to a minimum. The minimum distance, 13', between the centerline of each engine was selected to keep the size of the gears required for power transmission to a minimum and still provide clearance between the engines.

The starboard engine was reversed with the high pressure cylinder aft, so that the main condenser and air pump can be kept in their existing positions on each main engine without unnecessary added cost of installation. This necessitates a longer steam supply line, but this is negligible as compared to the changes required if the engines were placed in position with the high pressure ends of both engines forward. This reversal has to be effected by changing the power take-off from the low pressure to the high pressure end. This can

easily be accomplished since the main engine crankshaft is fabricated in sections.* Thus, the existing forward section of the high pressure crankshaft with eccentric would be removed and replaced by a new section with suitable flanges for power take-off.

Control of the engines is more complicated by this arrangement, but necessary extension rods can be designed to meet the control requirements. A suggested method for control of the main engines could be a long shaft between the engines with worm gears for operating each valve wheel simultaneously. The control station would be forward of the main engines on the centerline of the ship.

6. With the given engine spacing of 13' to accomplish the required speed changes by a single reduction, i.e. from 76 RPM of engines to 85 RPM of propeller shaft, the diameters of the gears must be 82.4" for the two engine pinions and 73.6" for the shaft bull gear.

The centerline of the reduction gear has been located at frame 109. For a generous allowance of space, the gears were designed with a loading factor of 50, and bearing pressures of approximately 150 pounds per sq. in. The overall length of the gears and bearings is 57". In the preliminary plan view of gears, Fig. 6, allowance has been made for installing flexible couplings between the main engines and the gears. The minimum space allowed is 21 5/8". The space forward of the reduction gear on the centerline to the main engines of

*Reference 8 plate 5928-2, No.15

47 1/2" is ample for a thrust bearing installation. Not only will the couplings offer means of disconnecting either main engine from the main shaft in case of breakdown, but also they provide some means of separating the propeller excited and engine excited vibrations.

In order to remove the gear casing for inspection or maintenance the existing thrust recess overhead must be raised approximately 5' 3". Also the former thrust recess must be widened to 33' 6" and lengthened to 10' to permit installation of the gears. This allows suitable room for the lube oil pump and lube oil purifier which are required for the gears to be installed in this space. The diameters of the gears require a cut out in the engineroom floor for the lube oil sump to be located beneath the gears. Lube oil storage tanks can be located aft of the gears on either side of the line shaft to provide necessary additional lube oil capacity.

7. Two main circulating pumps have been located on each side of the main engines. To keep the bilge injections from interfering with the turn of the bilge they must be limited in location to 21' off the centerline of the ship. Therefor, they were placed at this distance athwartships and forward of each main circulating pump to limit the length of piping to the pumps. The ballast and general service pump has been moved beside the existing fire and bilge pumps to make room for the main engines. Three fuel oil service pumps are required, two of these pumps can be used continuously with the

third as a standby. Four of these pumps do not seem necessary for this installation since the pumps are rugged, and an extra pump would usurp valuable space. However, four main feed pumps are required for safety requirements and to preserve split plant operation, if required. Of the two existing feed pumps, the inboard pump must be moved alongside the one outboard to allow for main engine relocation. The two new feed pumps are located on the starboard side. An extra feed heater is also needed close to the starboard fuel oil settling tank.

In the upper level space has been allowed for four generators to give sufficient capacity for the former armament installation which required four generators. The Storeroom and Workshop on this level has been reduced 4' in width as a result of the new machinery installation.

8. The size of the new line and tail shafting was determined using the American Bureau of Ships rules. Allowing slight margins, the final dimensions are 15.25" and 17" respectively. The former shafting was 13.5" for line shaft and 15 1/4" for the tail shaft. This proposal for new shafting will increase the overall cost, but knowing that the existing Liberty Ships have had considerable trouble with their shafting, a new installation seems to be warranted. Further discussion in the choice of size of shaft is included in item 10.

9. With the increase in shaft size, the bearings must be renewed in the line shafting. Also a new stern tube is necessary since the tail shaft has been increased to 17". Using

the American Bureau of Ships rules, the length of bearing and thickness of shaft liner have been determined. Fig. 11, Details of Stern Casting, has been drawn using these dimensions as a beginning, and closely approximating the thickness of the bushing and bearing strips from those on the existing Liberty Ships. The stern casting need not be renewed, but can be bored out for the new stern tube.

10. For the propeller calculations the first trial was made assuming an RPM of 120. This assumption was based on the fact that by increasing the RPM to this figure, it might be possible to retain the existing shafting. From this point on, the RPM was decreased to ascertain any gain in efficiency until the maximum allowable propeller diameter was reached. This showed that a gain in propeller efficiency of 7.5% was available by this process. Thus for such a tremendous gain in propeller efficiency it was decided that it would be well worth while to install new shafting to realize this gain. Final choice of propeller is Troost's B 4.55 series, 18' diameter, $H/D=1.10$.

By using an 18' diameter propeller, three additional inches of tip clearance would be allowed over that of the existing propellers. This allowance was made because of the increase in power delivered to the screw. This factor along with the increased diameter of the new shafting may be the answer to some of the shafting and propeller problems that have existed on these ships.

11. The preliminary length investigation revealed that

a speed of 15 knots could be obtained with the doubled power if the bow were lengthened a minimum of 20'. However, by comparison to Baker's models of good form * of corresponding block coefficient, it was found that for the characteristics of the new bow and old stern to be compatible at the increased speed, a bow length increase of 20' to 30' was indicated. Thus an increase of 24' was decided upon and a new set of bow lines prepared by fairing into the lines existing from Station 3 aft.

Good practice would indicate a half angle of entrance of 18° at the designer's load waterline for the assumed prismatic coefficient; however a half angle of entrance of 16° was chosen to produce a finer entrance. A raked stem with cut up was decided upon to improve seaworthiness. With the 20° raked stem, the waterlines above and below the designer's waterline could maintain the chosen half angle of entrance making the bow sections V-shape. Cut up from existing frame 15, 53' 7" from the new forward perpendicular, was used to eliminate inaccessible regions, to cut away useless surface area, and to provide for better flow.

The net result of finer entrance, raked bow, and cut up is expected to be a higher sustained sea speed with less danger of slamming in rough weather.

12. The changes in displacement and other curves for the bow changes are clearly illustrated in Fig. 14. The net result of the additional length amounts to an increase in

* Reference 11, p. 127

displacement of approximately 250 tons at the 27' waterline.

13. The coefficients for the new hull form at the 27.15' waterline indicate a reduction in C_p from .76 to .74 which is rather high for ships of the desired speed indicating that the conversion will be overdriven. This was another reason for choosing the finer entrance angle over that indicated by good practice. The block coefficient was reduced from .75 to .73 indicating that speed keeping in rough weather has been materially aided. The LCB has been changed in such a manner that it is almost exactly at the new midship section; this is considered a very favorable position for the new speed. Other coefficients indicate that the entrance has been lengthened as well as fined to aid in attaining the higher speed. The stern remains unchanged since it is considered a favorable shape for the increased speed.

14. The new floodable length curve illustrates that neither the lengthening of the machinery space nor the lengthening of #1 Hold jeopardized the one compartment standard.

15. The profile of the new bow shows the new arrangement. The only major difference from the former arrangement is in the deep tanks which are now included as fuel oil tanks.

16. The increase in light displacement from 3390 tons to 3868 tons is due largely to the additional machinery. Of the 478 tons added, machinery changes accounted for the following: Boilers 130 tons, Main Engines 140 tons, Shafting 14 tons, Reduction Gear 12 tons, and Machinery Liquids 45 tons.

17. The fuel oil capacity was increased from 1819 tons

to 2453 tons to provide for the increased fuel consumption resulting from increasing the power. Increases are derived from the larger double bottom tank #1, using deep tanks #1 and #2 for fuel oil, and from the larger settling tanks. Some fuel oil capacity was lost by enlargement of the thrust recess in #3 Deep Tank to accommodate the reduction gears.

18. The decrease in grain cubic from 562,608 cu. ft. to 550,142 cu. ft. and in bale cubic from 499,573 cu. ft. to 494,446 cu ft. is largely a result of a much shorter #3 Hold. Gains were made in #1 Hold, and #1 and #2 Deep Tanks, with losses in #3 Hold and #3 Deep Tank.

19. The final coefficient of EHP bare to SHP at the engine of .78 was based on the following known and assumed quantities: Propeller efficiency = .671 from propeller calculation; wake fraction = 0.250 and thrust deduction = .085 from existing Liberty Ship tests; transmission efficiency = .99 assumed; relative rotary efficiency = 1.00 assumed; and appendage allowance of 4%.

20. The final EHP and SHP curves were derived from Taylor's Standard Series * using the coefficient obtained in Item 19 above. They indicate a maximum speed of 15.3 knots at 4600 SHP or 2300 SHP per unit; or a service speed based on 80% of maximum power of 14.5 knots at 3680 SHP or 1840 SHP per unit. Since the units are reciprocating engines with a large factor of safety, it is assumed that they can be operated at or near maximum power for extended periods of time,

* Reference 13

and thus a sustained speed of 15 knots at 4200 SHP or 2100 SHP per unit is not an unattainable goal. The boilers in no way would be controlling in that each one is capable of sustained operation at 30% above maximum engine power requirements.

21. The range of 17,500 miles at 15.3 knots compares favorably with the original maximum range of 20,000 miles at 12 knots. The fuel consumption of the conversion is 1.25 barrels per mile at 15.3 knots compared to .80 barrels per mile at 12 knots for the existing ship.

V. CONCLUSIONS

One of the principal factors effecting the overall evaluation of this plan cannot be completely discussed at this writing. This is the cost involved in the conversion. Refined estimates of cost are expected at a later date from two reliable firms in the shipbuilding industry, and will be included in APPENDIX M if they are received in sufficient time. One of these estimates will be based on the consideration that material for the conversion will be delivered to the conversion yard; i.e. that material needed from the scrapped ship will be supplied by the government. Furthermore, that any costs involved in any necessary machinery reconditioning are not included as they are indeterminable.

To date, two rough estimates have been received from two other shipyards based upon a brief description of our proposal, see letter in APPENDIX M. These estimates are "Two Million Dollars, Plus or Minus", and "a very rough estimate . . of \$1,500,000". In view of these estimates, it is considered feasible to attempt such a conversion for improvement of the Liberty Ship.

Mr. Douglas C. MacMillan has proposed a conversion for an 18 knot Liberty Ship * by using a completely new power plant with lengthening and refining of the bow. It is believed that his proposal is designed to make them a competitive ship for actual Merchant Marine operation since he also considers improvements of cargo handling and living quarters.

*Reference 16

It is acknowledged that the existing Liberty Ships may be deficient in living quarters and cargo handling, and that these items should not go unnoticed; however, our proposal was clearly based on a minimum change to the existing ship necessary only to make it capable of higher speeds.

One distinct advantage of our proposal of 15 knots over that of 18 knots would be in the homogeneity of the reserve fleet. With the 18 knot conversion operating in company with Victory Ships they would have to reduce speed to 15 or 16 knots when in convoy; clearly the added expense of converting to 18 knots would be entirely wasted in this case. Thus by converting only to the 15 knot range, as in our proposal, the entire reserve fleet of Victory and Liberty Ships would be placed nearly on an equal level with no ship having to sacrifice much in available speed to maintain convoy operations. The role of 18 knot ships should be left for new ships with a full service life ahead.

Even though no refined cost estimate has been received, it is felt that this proposal represents the least expensive conversion cost for producing a faster Liberty Ship. A minimum of new material is needed, and the greatest cost would be in labor of the type and scope that would be required for any rational conversion to achieve the same goal of 15 knots.

The alternative, eliminating this proposal's cost of reduction gear and new shafting by going to twin screw with existing shafting, was vetoed early in the investigation for two reasons. First, some of the gain in horsepower would be

offset by a reduced propulsive coefficient. The overall efficiency of a twin screw plant is always considerably less than that of a properly designed single screw installation unless the choice of propeller diameter for the installed horsepower is severely limited. Secondly, the cost of the major internal and external changes required for running two new shaft lines with elimination of the existing shaft line were considered not much less than the cost of reduction gears and new shafting. Thus the overall balance showed desirability for maintaining single screw propulsion, and to this end considerable attention was given to placing the two main engines as close as possible for making the reduction gears a reasonable size. The method by which this is done is considered unique and came about after many unsuccessful schemes were tried.

The need for a new and longer bow should be clearly evident by this time. The resistance of the existing hull form is not only prohibitive of higher speeds, but also, if they were attained prohibits their being maintained in any sea conditions other than the most favorable. Thus the new bow was designed to ease the attainment of the higher speed, and also to aid in maintaining that speed under adverse sea conditions. If the doubled power were installed in the existing Liberty hull form, a maximum speed of approximately 14.5 knots could be attained. With the new hull form and doubled power, 15.3 knots can be attained. Thus the gain in speed for the new hull form is approximately $3/4$ knot over the

existing hull form.

The amount by which Hold #3 was shortened leaves some doubt as to its utility after conversion. This is the only place in which the dry cargo capacity may have been jeopardized. If this hold is considered too short for proper cargo handling and stowage, it could be converted into a deep tank for carrying liquid cargo, or else made into a refrigerated cargo space.

The excessive fuel consumption of the existing Liberties was one attribute by which they were deemed unfit for competitive merchant ship operation. Since this conversion embodies the use of two of these fuel consuming plants, it can reasonably be understood that this conversion was in no way designed to place the ship in competition with operating merchant fleets. It must be definitely understood that the whole purpose was to devise a plan for conversion that would provide the least drain of material and expense to prevent the present Liberties from being "sitting ducks" in the event of any future conflict.

If they were to be converted for merchant fleet competition a scheme of the type employing only installation of Fiat diesels which is now being done in Italy * is suggested. However, the domestic cost of machinery and labor involved would probably prohibit such an installation.

A check of hull strength # showed that the existing

* Reference 15

Appendix H

Liberties have sufficient strength to meet requirements for the designed draft of 27.15'. However, in view of the many hull fractures in this class ship, approved methods of flat bar stiffening of the decks employing use of crack arrestors should be fitted to those vessels on which this alteration has not been accomplished.

The final conclusion would be that our plan is a possible means of conversion to increase the speed to approximately 15 knots at a minimum of cost.

VI. RECOMMENDATIONS

The first and foremost recommendation would be that a model test, including self propulsion tests, be made of the new hull form to check conclusively the approximations and calculations made in this proposal before any attempt is made to try this plan in actuality. Also, in light of the fact that this report is considered more of a preliminary design evaluation, in many instances before undertaking the procedures outlined, more investigations should be made for further checks of the results listed. Such items in this category would be the reduction gear and shafting; more complete vibration analysis of the propulsive system to aid in designing flexible couplings and/or vibration dampers; and detailed plans for construction of the new bow. Piping arrangements for the new machinery locations, control and support of the main engines, and boiler foundations are also suggested for further investigation for completion of a contract design.

VII. APPENDIX

APPENDIX A

PROPELLER SELECTION

Screw series, B 4.55, is chosen for its better cavitation characteristics and its apparent freedom from singing. A large blade area ratio, $F_a/F = 0.55$, is selected with the expectation that the blades will be highly loaded.*

Since the driving power of the ship is doubled, IHP = 5,000, it is necessary, first, to determine the required revolutions per minute, if the existing shafting is to be used.

From American Bureau of Shipping rules**, the required revolutions per minute for the existing shafting with the new increase in power is given by:

$$D = C \sqrt[3]{K_1 \text{ SHP}/N}$$

where

D= diameter of line shaft, inches = 13.5 in. existing.

C= 1 for line shafting

K_1 = 64, a factor for ocean service

IHP= indicated horsepower = 5,000

SHP= shaft horsepower = $0.92 \text{ IHP}^\# = 4600$

$$\text{therefore } N = C^3 K_1 \text{ SHP} / D^3 = \frac{1 \times 64 \times 4600}{(13.5)^3} = 120 \text{ RPM}$$

* Reference 1, p. 198

** Reference 2, p. 130

Reference 3, p. 40

The following factors are needed prior to entering into the propeller charts:*

w = wake fraction

V_s = ship's speed, knots

V_a = intake velocity for the screw, knots

C_b = block coefficient

B_p = screw loading coefficient

P = power absorbed by the screw (in hp. of 76 Kgm/sec.)

From Taylor's equation for wake fraction, w , is:

$$w = -0.05 + 0.50 C_b = -0.05 + 0.50(0.73)$$

$$w = 0.315$$

From existing Liberty Ships #, $w=0.25$ at 14 knots. This latter wake fraction will be used, since it is more realistic. Assuming shaft friction loss to be approximately 4%, so that power delivered to the screw is:

$$P = 0.96 \times 4600 = 4420 \text{ DHP}$$

$$P(\text{corrected for metric system}) = 75(4420)/76 = 4360$$

In the B_p formula, however, the power in fresh water should be used, so that finally $P = 4360 / 1.025 = 4260$.

Decreasing the revolutions per minute 2% due to scale effect, N becomes $0.98 \times 120 = 118$ RPM (approximately 2 RPM less).

The intake velocity for the screw is:

$$V_a = V_s(1 - w) = 15(1 - 0.25) = 15 \times 0.75 = 11.25 \text{ Knots}$$

$$\text{Now } B_p = N \times P^{0.5} / V_a^{2.5} = 118 \times \sqrt{4260} / (11.25)^{2.5}$$

$$B_p = 18.1$$

* Reference 1 p. 207

Reference 4

Entering the propeller chart for Screw series B.4.55

$$\delta = 167 = N \times D / V_a \text{ velocity coefficient}$$

D = propeller diameter in feet

The velocity coefficient should be diminished by a certain percentage which is related to the shape of the after body*. Deduction is assumed to be 5%.

$$\delta' = 0.95 \delta = 0.95 \times 167 = 158.5 = \text{corrected vel. coeff.}$$

$$H/D = 0.97 \text{ pitch ratio where } H = \text{face pitch}$$

$$\eta_p = 62.5\% \text{ propeller efficiency}$$

$$D = \delta' \times V_a / N = 158.5 \times 11.25 / 118 = 15.0 \text{ ft.}$$

Since the propeller diameter is too small as compared to that existing on the Liberty Ships (18' 6"), a larger propeller is required. One proposal is suggested to meet this demand. By decreasing the required shaft RPM sufficiently, a propeller approximately the same size as the present propeller may be found.

Using the relationship for the new B_p 's,

$$B_p = N_{\text{new}} \times 18.1 / 118$$

and the given information, the following characteristics may be determined from the propeller chart for each trial of N.

Trial	N	N _{corr}	B_p	δ	δ'	H/D	η_p	D
1	100	98	15.0	151	143.3	1.07	65.0	16.5'
2	85	83	12.73	140	133	1.10	67.1	18.0'

No further reduction in RPM is considered since the diameter of the propeller would become too large. Also, a slightly larger tip clearance is provided over that for the existing propeller.

*Reference 1, p.235

The gain in horse power over that for N= 120 RPM is:
 $(.671 - .625)/.625 = .0737$ or approximately 7.5% gain.

CAVITATION CHECK FOR PROPELLER

The following factors are known:

Draft T= 27.15 ft. x .3048 = 8.28 m.

Height of center of shaft above base

$$E = 10.83 \text{ ' } \times .3048 = \underline{3.30 \text{ m.}}$$

Wave height $T - E = 4.98 \text{ m.}$
 $\underline{0.743 \text{ m.}}$

Wave head above center of shaft = 5.723 m.

Hydrostatic pressure in sea water
 $(5.723 \times 1025) . . . = 5870 \text{ Kg/m}^2$

(Atmospheric pressure - vapor pressure, e) = 10100 Kg/m²

(Static pressure at center of
screw shaft - e) = $(P_o - e) = 15,970 \text{ Kg/m}^2$

Intake velocity $v_e = 15(1-0.25) \times 0.5144 = 5.78 \text{ m/sec.}$

Hence, the cavitation number becomes:

$$\sigma_o = \frac{P_o - e}{\frac{1}{2} \rho v_e^2} = 15970 / (.5 \times 104.5 \times 5.78^2) = 9.15$$

where ρ = density of fluid, $\text{Kgm}^{-4}\text{sec}^2 = 104.5$

Assuming $\xi_a = 1.025$ relative rotary efficiency of the screw

$\eta_{ps} = \eta_p \times \xi_a$ = screw efficiency behind the ship

$$\eta_{ps} = 0.671 \times 1.025 = \overset{0.671}{\underline{0.689}}$$

The thrust, S, may be calculated from the power intake
velocity:

$$S = \frac{\text{DHP} \times 75 \times \eta_{ps}}{v_e} = \frac{4420 \times 75 \times \overset{0.671}{\underline{0.689}}}{5.78} = 38,500 \text{ Kgs.}$$

According to the chart for cavitation limits*

$$\frac{S/F_p}{P_o - e} \approx 0.39 \quad \text{Ratio of thrust per unit of projected blade area to the static pressure above the center of the screw shaft.}$$

$$\frac{S}{F_p} = 0.39 \times 38,500 = 15,000 \text{ kg/m}^2$$

$$\text{Hence } F_p = \frac{38,500}{15,000} = 2.56 \text{ m}^2 \quad \text{Minimum projected blade area below which cavitation occurs.}$$

For the screw series chosen, $F_a/F = 0.55$, Ratio of expanded blade area to disc area of the screw.

$$\text{Diameter} = 18' \times 0.3048 = 5.49 \text{ m.} \quad H/D = 1.10$$

$$F_p/F_a = 1.067 - 0.229 H/D \quad \text{Taylor's equation for ratio of projected blade area to the expanded blade area.}$$

$$F_p = 0.55 \times (\pi/4) \times (5.49)^2 [1.067 - 0.229 \times 1.10]$$

$$F_p = 10.6 \text{ m}^2 \text{ for } F_a/F = 0.55$$

Therefor no cavitation is expected for the propeller chosen.

By Eggert's method[#] another cavitation check can be made. It is possible by this method to determine the revolution per second at which the loss of thrust due to cavitation begins. The formula is:

$$k (\pi n d)^2 = 10.7 h \frac{1 + 4b}{\alpha + c} \quad \text{or}$$

$$n^2 = \frac{10.7 h}{k \pi^2 d^2} \times \frac{1 + 4b}{\alpha + c} \quad \text{where:}$$

n = the revolutions per second at which loss of thrust begins.

d = the screw diameter at 0.9 radius, R ; $d = 0.9D$

*Reference 1 p. 186

#Reference 1 p. 180

h = the total head, in feet of water, above the screw axis (being the sum of the water head and the atmospheric head, the latter being equal to 33 feet of sea water)

$b = \ell_m/D$ = the mean blade-element length ratio

α = the angle of attack at $0.9R = \frac{a S_n}{2 \pi k}$

$C = S/\ell$ = the blade-thickness ratio at $0.9R$

$k = 1 + \left[\frac{a}{\pi} (1 - S_n/2) \right]^2$ where:

a = the pitch ratio at $0.9R = H/(0.9D)$

S_n = the slip ratio at $0.9R = 1 - \frac{v_e}{n H}$

water head = $5.723 \times 1025 = 5870 \text{ kg/m}^2 = 19.25 \text{ ft. of water}$

atmospheric head = $33.00 \text{ ft. of water}$

Total head = $52.25 \text{ ft. of water}$

$k = 1 + \frac{a^2}{\pi^2} (1 - S_n/2)^2$

$H/D = 1.10 \quad H = 1.10 \times 5.49 = 6.04 \text{ m.}$

$a = 1.10/0.9 = 1.22$

$S_n = 1 - \frac{v_e}{n H} = 1 - \frac{5.78 \times 60}{85 \times 6.04} = 0.325$

$k = 1 + \frac{(1.22)^2}{3.14^2} (1 - .162)^2 = 1 + (.151) (.702)^2 = 1.106$

$d = 0.9 \times 18 = 16.2 \text{ ft.}$

$b^* = \ell_m/D = 0.259$ assuming $d_n/D = .167$ boss diameter ratio.

$\alpha = \frac{a S_n}{2 \pi k} = \frac{1.22 \times 0.325}{2 \times 3.14 \times 1.106} = .0569$

$c^\# = s/\ell$ at $0.9 R$ ℓ = chord length; s = blade thickness;
4 blades; $D = 5.49 \text{ m.}$

ℓ_{\max} at $0.6R = 0.2187 D = 1.20 \text{ m.}$

ℓ at $0.9R = 0.72 \ell_{\max} = 0.865 \text{ m.}$

* Reference 1 p. 177

Reference 1 p. 204

$$S_{\max} = 0.045 \text{ D} = .247 \text{ m.}$$

$$S/D \text{ at } 0.9R = .0072$$

$$S = .0395$$

$$c = s/\rho = .0395/.865 = .0457$$

$$n^2 = \frac{10.7 \times 52.25}{1.106 \times (3.14)^2 \times (16.2)^2} \times \frac{1 + 4(0.259)}{.0569 + .0457} =$$

$$n^2 = .195 \times \frac{2.036}{.1026} = 3.86$$

$$n = \sqrt{3.86} = 1.97 \text{ rev. per sec.} = 118 \text{ rpm}$$

Since the maximum revolutions per minute for the propeller chosen is to be only 85 rpm; it is not expected that the propeller will cavitate.

Lerb's method is not used since the characteristics of this screw lie outside the range examined by him.

The characteristics of the propeller selected are:

Troost's B. 4.55 series

Diameter = 18'

Pitch/Diameter, H/D = 1.10

Ratio of expanded blade area to disc area, $F_a/F = 0.55$

Propeller efficiency, $\eta_p = 67.1\%$

Designed RPM = 85

Screw loading coefficient at designed conditions,

$$\beta_p = 12.73$$

COEFFICIENT FOR PROPULSION

To calculate the coefficient $EHP_{\text{bare}}/SHP_{\text{engine}}$ the following known and assumed quantities were used:

t = thrust deduction = .085 from existing Liberty Ship*

w = wake fraction = 0.25 from existing Liberty Ship

e_{rr} = 1.00 assumed relative rotary efficiency

e_t = .99 assumed transmission efficiency

e_p = .671 calculated propeller efficiency

Appendage allowance = 4% assumed.

The following relations are used in determining this coefficient:

Propulsive coefficient = $\frac{EHP}{PHP}$ = $e_h \times e_p \times e_{rr}$ where

$$e_h = \frac{1 - t}{1 - w} = \frac{1 - .085}{1 - 0.25} = 1.22$$

$SHP_{engine} \times e_t = PHP$ and $EHP = 1.04 EHP_{bare}$

$$\begin{aligned} \text{Therefor } \frac{EHP_{bare}}{SHP_{engine}} &= \frac{e_h \times e_p \times e_{rr} \times e_t}{1.04} \\ &= \frac{1.22 \times .671 \times 1.0 \times .99}{1.04} = .78 \end{aligned}$$

* Reference 4

APPENDIX B

SHAFTING AND STERN TUBE SIZE ESTIMATION

LINE SHAFT

Since the proposed shaft RPM is 85 for 76 RPM of the main engines, the existing shafting will not be adequate. From the line shaft formula* the least diameter shaft will have to be:

$$D = C \sqrt[3]{\frac{K \times \text{SHP}}{N}} = 1 \sqrt[3]{\frac{64 \times 4600}{85}} = 15.1 \text{ inches}$$

On this basis 15.25 inches is selected for line shaft diameter.

TAIL SHAFT

The least tail shaft diameter is determined by the following formula#:

$$T = d + P/C \text{ where;}$$

T = diameter of tail shaft in inches

d = diameter of line shaft in inches

P = diameter of propeller in feet

C = 12 when the shaft is fitted with a continuous liner.

$$T = 15.25 + 18.0/12 = 16.75 \text{ inches (least diameter)}$$

$$T = 17.0 \text{ inches assumed.}$$

* Reference 2 p. 130

Reference 2 p. 127

LINER THICKNESS

The existing liner thickness for 15 1/4" diameter tail shaft is approximately $25/32" = 0.781"$

To calculate the new liner thickness American Bureau of Ships' rules* are used. The least thickness of liners in way of bearings fitted to the tailshaft of ocean going vessels is as follows:

$$t = T/25 + 0.20 \text{ where:}$$

t = thickness of liner, inches

T = required diameter of tailshaft, inches

$$t = 17/25 + 0.20 = 0.88 \text{ inches}$$

The thickness of continuous liners between bearings should not be less than 3/4 of the thickness t , determined above:

$$t_{\min.} = 0.75 \times 0.88 = 0.66 \text{ inches}$$

A liner of 7/8 inches (0.875 in.) from above considerations seems adequate for the new tail shaft diameter.

The length of the bearing next to and supporting the propeller should not be less than 4 times the required tail shaft diameter**:

$$l = 4 \times 17 = 68 \text{ inches} = 5' 8"$$

In selecting the proposed stern tube dimensions, a clearance of 1/16" has been allowed for clearance between liners and lignum vitae#.

* Reference 2 p. 127

** Reference 2 pp. 263, 264

Reference 6 p. 43 - 48

ESTIMATION OF TORSIONAL CRITICAL

Weight of propeller = 23,500 lbs. (assumed from existing propeller on Liberty Ship).

Diameter = 18'

Radius of gyration of propeller* = $0.21 \times 18 = 3.78'$

The approximate moment of inertia, I_p , of the propeller equals:

$$\frac{23,500 \times (3.78)^2}{32.2} = 10,420 \text{ ft.-lb. sec.}^2$$

The value for I_s for a solid steel shaft can be determined from the following expression[#]:

$$I_s = 6 \times 10^{-6} L D^4 \text{ ft. lb. sec.}^2 \quad \begin{array}{l} \text{(the weight per cubic} \\ \text{inch of steel has been} \\ \text{incorporated)} \end{array}$$

$$I_s = 6 \times 10^{-6} (12 \times 148.7) (15.25)^4 \text{ (Dimensions in inches)}$$

$$I_s = 579 \text{ ft.- lb. sec.}^2$$

The shaft length for this case is an equivalent length of shafting of 15.25" diameter. To simplify the work it has been assumed that the new shafting of 154.8' is made up of two sizes; i.e. 137.5' of 15.25" diameter, and 17.3' of 17" diameter.

In terms of equivalent of 15.25" shafting:

$$L = 137.5 + 17.3 (15.25/17)^4$$

$$L = 148.7'$$

* Reference 7 p. 293

Reference 3 p. 55

By approximation the total moment of inertia of the combination is:

$$I = 1.25 I_p + I_s/3 = 1.25 \times 10,420 + 579/3 =$$

$$I = 13,243 \text{ ft.-lb. sec.}^2$$

The stiffness constant can be determined from the following:*

$$k = \frac{\pi (D)^4 \times 12 \times 10^6}{12 \times 32 \times L} = \frac{98,500 D^4}{L} \text{ ft.-lb./radians}$$

$$k = \frac{98,500 \times (15.25)^4}{12 \times 148.7} = 2.99 \times 10^6$$

The period is:

$$T = 2\pi \sqrt{I/k} = 2\pi \sqrt{(13,243)/(2.99 \times 10^6)}$$

$$T = 0.42 \text{ secs.}$$

or the frequency $f = 1/0.42 = 2.38$ cycles/sec. This corresponds to $2.38 \times 60 = 143$ cycles/min. torsional vibration frequency.

Disturbances due to blade frequency, since a four-bladed propeller has been selected, would occur at $143/4 = 35.7$ shaft rpm. Since the full power RPM of the shaft occurs at 85 rpm, it is assumed that there would not be enough energy due to blade action to cause any trouble since the torsional frequency occurs very low in the power range.

* Reference 3 p. 49

ESTIMATION OF HULL CRITICAL

The two-noded vertical frequency of a ship can be approximated by the following:*

$$N = C \sqrt{\frac{I}{D L^3}} \quad \text{where}$$

N = vibrations per minute

D = the displacement or weight in tons
= 14,175 tons at draft = 27.15'

L = length of ship, feet = 440'

I = moment of inertia of the midship section in
ft.²in.² = 448,000 ft.²in.² from APPENDIX H

C = 1.39×10^5 for a free-free bar of uniform cross-section.

$$N = 1.39 \times 10^5 \sqrt{\frac{448,000}{(14,175) (440)^3}}$$

$$N = 1.39 \times 10^5 \times .610 \times 10^{-3}$$

$$N = 85 \text{ vibrations per minute}$$

Using the average value "best for all types" of the Schlick coefficient, C, equal to 1.32×10^5

$$N = 80 \text{ vibrations per minute}$$

This estimated hull critical occurs at or very close to full speed operating RPM. Since the effect of butt strap stiffening was not accounted for in the inertia of the midship section, the value of the hull critical may be raised enough to eliminate vibration difficulties.

* Reference 27 p. 2

However, since these vibration critical values are approximate to $\pm 5\%$, the hull critical may be outside the speed range, or equally so, it may occur very close to full speed condition. In view of the fact that this critical varies not only with the depth of water in which operating, but also with the speed of operation and loading conditions; under some circumstances no difficulty may be encountered. Since this critical is estimated to occur at the extreme upper limit of speed and at maximum displacement, reduction in either one of these factors would alleviate the situation.

It can be concluded that if vibration difficulties exist at or near full speed, they will probably be due to the hull critical.

APPENDIX C

REDUCTION GEAR DESIGN

Since the absolute minimum distance between the centerlines of the two reciprocating engines is 13', it is apparent that large size gears are necessary to attain single reduction. The two gears on each engine must be the same size since each main engine is exactly 6' 6" from the shaft centerline. The gear on the shaft will necessarily be smaller than those on each engine. The engine speed is 76 RPM; designed shaft RPM is 85.

The diameter of respective gears can be determined as follows:

Let r_1 = radius of gear on shaft, inches

r_2 = radius of gear on either engine, inches

then $r_1 + r_2 = 6' 6" = 78"$

and $r_1/r_2 = 76/85$

$r_2 = 85/76 \quad r_1 = 1.12 r_1$

therefor $r_1 + 1.12 r_1 = 2.12 r_1 = 78"$

$r_1 = 36.8" \quad D_p = \text{diameter of pinion} = 73.6"$

$r_2 = 41.2" \quad D_g = \text{diameter of gear} = 82.4"$

A loading factor*, K = 67, is assumed which is a recommended value for merchant ships operating more or less at continuous full power.

* Reference 7 p. 242

The diameter of the gear in terms of the known quantities is as follows:*

$$D_g = 3 \sqrt{\frac{126,050}{(L/D)_p K_1} \times \frac{SHP}{RPM_g} \times R_2 (R_2 + 1)} \quad \text{where}$$

$(L/D)_p$ = length to diameter ratio of pinion

RPM_g = revolutions per minute of the gear = 85

R_2 = ratio, diameter of gear/diameter of pinion = $85/76 = 1.12$

K_1 = loading factor, assumed = 67

SHP = shaft horse power per mesh = 2300

Solving for $(L/D)_p$

$$(L/D)_p = \frac{126,050}{67} \times 2300 \times \frac{1}{76} \times \frac{(1.12)(2.12)}{(82.4)^3}$$

$$(L/D)_p = 0.242$$

The length of the gear face can be determined from:

$$L = (L/D)_p \times D_g/R = 0.242 \times 82.4/1.12 = 17.8" \quad (K=67)$$

or if:

$$K = 100 \quad (L/D)_p = 0.179 \quad L = 13.15"$$

$$K = 50 \quad (L/D)_p = 0.325 \quad L = 23.9"$$

For the actual arrangement the length, L, was selected as 24", which approximates a loading factor of 50. This was assumed so that the gears would take as much room as possible in this preliminary design. Any need for space which may be necessary for other functions could come from a shorter length dimension necessary for the gears. Approximately 6" decrease in length of the gears can be realized by an increase in the loading factor to 67.

* Reference 7 p. 241

In order to determine the bearing sizes, the following information is necessary:

Estimation of weight of gears:

$$L = \text{face width, inches} = 26"$$

$$\text{Diameter} = 82.4"$$

$$\begin{aligned} \text{Weight}_{\text{gear}} &= \text{coeff.} \times L \times (\text{Diameter})^2 && \text{A suitable coefficient for low} \\ &= .038 \times 26 \times (82.4)^2 && \text{speed gears, not} \\ &= 6,700 \text{ lbs.} && \text{including shafts,} \\ &&& \text{is .038} \end{aligned}$$

$$\begin{aligned} \text{Weight}_{\text{shaft}} &= \text{Density} \times \text{volume} = 390 \times \frac{\pi}{4} \left(\frac{14.25}{12} \right)^2 \times 4.75 \\ &= 2055 \text{ lbs.} \end{aligned}$$

$$\text{Weight}_{\text{total}} = W_g + W_s = 8755 \text{ lbs. (gear and shaft for one engine)}$$

Estimation of weight of pinion:

$$\text{Diameter} = 73.6" = D_p$$

$$\begin{aligned} \text{Weight}_{\text{pinion}} &= \text{Weight}_{\text{gear}} \left(\frac{D_p}{D_g} \right)^2 \\ &= 6,700 \left(\frac{73.6}{82.4} \right)^2 \\ &= 5,350 \text{ lbs.} \end{aligned}$$

$$\begin{aligned} \text{Weight}_{\text{line shaft}} &= \text{Weight}_{\text{shaft}} \left(\frac{D_{\text{line shaft}}}{D_{\text{shaft}}} \right)^2 \\ &= 2055 \left(\frac{15.25}{14.25} \right)^2 \\ &= 2360 \end{aligned}$$

$$\begin{aligned} \text{Weight}_{\text{total}} &= W_p + W_{ls} = 5,350 + 2,360 = \\ &= 7710 \text{ lbs. (pinion and line shaft)} \end{aligned}$$

Assuming a pressure angle of $15^\circ = \theta$

$$P = P_t / \cos \theta = \frac{126,050}{\cos \theta} \times \frac{\text{SHP}}{\text{RPM}_g} \times \frac{1}{D_g} \quad \text{where}$$

P = total load on gears, lbs.

P_t = transmitted or tangential load on the gear teeth, lbs.

$$P = \frac{126,050}{\cos 15^\circ} \times \frac{2300}{76} \times \frac{1}{82.4} = 48,000 \text{ lbs.}$$

From Fig. 5, the maximum reaction force, R , is 56,700 lbs.

By making the length of each bearing 15" and assuming 14.25" diameter shafting, the bearing pressure is:

$$P = R/A = 56,700 / (30 \times 14.25) = 133 \text{ psi/bearing}$$

Since a generous coefficient was selected to determine the weight of the gears, the size of bearings and bearing pressures seems to be ample for the design.

From Fig. 5 for this arrangement of gears, the loads on the pinion cancel for ahead and astern operations. In case of one unit emergency operation these loads do not cancel, but only one is active, and less than the load on the gear. The same size bearing has been assumed for the pinion thus providing ample strength and support.

APPENDIX D

PRELIMINARY LENGTH INVESTIGATION

For the preliminary length investigation, the existing Liberty Ship sectional area curve was stretched out at the forward end, and calculations made from the area curves thus obtained for the necessary coefficients to perform EHP calculations by Taylor's Standard Series.* The sectional area curves are illustrated in Fig. 16. These calculations are shown for all preliminary alterations on the following calculation sheets.

Plots of resistance coefficients and EHP versus speed obtained from Taylor's Standard Series are illustrated in Fig. 17 and Fig. 18. The calculation sheets for these values are not shown since they are strictly interpolations for the preliminary investigation and not for the final results. Sample calculations for this process are illustrated in APPENDIX E for the final hull form.

Assuming a propulsive coefficient of .75 and SHP of 4400 for full speed, the corresponding value of EHP is 3300. Using this value to enter Fig. 18, the following speeds can be attained:

Liberty Ship	(length = 416')	. . . . .	14.3 knots
Alteration #1	{10' added}	. . . . .	14.7 knots
Alteration #2	{20' added}	. . . . .	14.9 knots
Alteration #3	{30' added}	. . . . .	15.1 knots
Alteration #4	{40' added}	. . . . .	15.2 knots

* Reference 13

Thus it is assumed that a speed of 15 knots could be attained with an additional length of 20' to 30'. The additional length of 24' was selected for attainment of the 15 knot goal making the new length between perpendiculars 440'.

ALTERATION #1 COEFFICIENTS AND CHARACTERISTICS

STA	A/A _x	SM	f(A)	\bar{y}	f(LM)
0	0	1	0	+10	+ 0
1	.215	4	.860	+ 9	+ 7.740
2	.475	2	.950	+ 8	+ 7.600
3	.753	4	3.012	+ 7	+21.084
4	.900	2	1.800	+ 6	+10.800
5	.963	4	3.852	+ 5	+19.260
6	.990	2	1.980	+ 4	+ 7.920
7	.998	4	3.992	+ 3	+11.976
8	1.000	2	2.000	+ 2	+ 4.000
9	1.000	4	4.000	+ 1	+ 4.000
10	1.000	2	2.000	0	+94.380
11	.998	4	3.992	- 1	- 3.992
12	.995	2	1.990	- 2	- 3.980
13	.985	4	3.940	- 3	-11.820
14	.955	2	1.910	- 4	- 7.640
15	.887	4	3.548	- 5	-17.740
16	.769	2	1.538	- 6	- 9.228
17	.606	4	2.424	- 7	-16.968
18	.400	2	.800	- 8	- 6.400
19	.170	4	.680	- 9	- 6.120
20	.020	1	.020	-10	- .200
$\Sigma f(A)$			45.288	$\Sigma f(LM)$	+10.292

$$\text{Length} = 426.4' \quad S = 21.32' \quad H = 27.15' \quad B = 56.9'$$

$$C_p = \frac{\Sigma f(A)}{60} = 0.755 \quad \text{L.C.B.} = \frac{\Sigma f(LM) \times S}{\Sigma f(A)} = \frac{+10.292 \times 21.32}{45.288}$$

$$\text{L.C.B.} = 4.85 \text{ ft. Fwd. } \emptyset$$

$$\Delta = \frac{S \Sigma f(A) \times A_x}{3 \times 35} = \frac{21.32(45.288)(1522)}{3 \times 35} = 13,996 \text{ tons}$$

$$\nabla = \Delta \times 35 = 488,810 \text{ cu. ft.} = \nabla$$

$$C_b = \frac{\nabla}{L B H} = .742$$

$$C_v = \frac{\nabla}{L^3} = 6.3 \times 10^{-3}$$

Total Length	L. ent.	Middle body	L. run
426'	41.5%	9.7%	48.8%

$$C_{pr} = .715 \text{ (existing)}$$

$$C_{pe} = .744 \text{ (calculated)}$$

ALTERATION #2 COEFFICIENTS AND CHARACTERISTICS

STA	A/A _x	SM	f(A)	\bar{y}	f(LM)
0	0	1	0	+10	+ 0
1	.193	4	.772	+ 9	+ 6.948
2	.412	2	.824	+ 8	+ 6.592
3	.663	4	2.652	+ 7	+18.564
4	.852	2	1.704	+ 6	+10.224
5	.950	4	3.800	+ 5	+19.000
6	.986	2	1.972	+ 4	+ 7.888
7	.997	4	3.988	+ 3	+11.964
8	.999	2	1.998	+ 2	+ 3.996
9	1.000	4	4.000	+ 1	+ 4.000
10	1.000	2	2.000	0	+89.210
11	.999	4	3.996	- 1	- 3.996
12	.995	2	1.990	- 2	- 3.980
13	.988	4	3.952	- 3	-11.856
14	.960	2	1.920	- 4	- 7.680
15	.898	4	3.592	- 5	-17.960
16	.783	2	1.566	- 6	- 9.396
17	.617	4	2.468	- 7	-17.276
18	.405	2	.810	- 8	- 6.480
19	.175	4	.700	- 9	- 6.300
20	.020	1	.020	-10	- .200
$\sum f(A)$			44.724	$\sum f(LM)$	+ 4.086

$$L = 436.8' \quad S = 21.84' \quad H = 27.15' \quad B = 56.9'$$

$$C_p = \frac{\sum f(A)}{60} = .745 \quad L.C.B. = \frac{\sum f(LM) \times S}{\sum f(A)} = 1.99' \text{ Fwd. } \infty$$

$$\Delta = \frac{S \times \sum f(A) \times A_x}{3 \times 35} = 14,152 \text{ tons}$$

$$\nabla = \Delta \times 35 = 495,320 \text{ cu. ft.}$$

$$C_b = \frac{\nabla}{L B H} = .734$$

$$C_v = \frac{\nabla}{L^3} = 5.93 \times 10^{-3}$$

Total Length	L. ent.	Middle body	L. run
436'	42.8%	9.6%	47.6%

$$C_{pr} = .715 \text{ (existing)}$$

$$C_{pe} = .723 \text{ (calculated)}$$

ALTERATION #3 COEFFICIENTS AND CHARACTERISTICS

STA	A/A _x	SM	f(A)	\bar{y}	f(LM)
0	0	1	0	+10	0
1	.157	4	.628	+ 9	+ 5.652
2	.355	2	.710	+ 8	+ 5.680
3	.589	4	2.356	+ 7	+16.492
4	.790	2	1.580	+ 6	+ 9.480
5	.925	4	3.700	+ 5	+18.500
6	.978	2	1.956	+ 4	+ 7.824
7	.994	4	3.976	+ 3	+11.928
8	.999	2	1.998	+ 2	+ 3.996
9	1.000	4	4.000	+ 1	+ 4.000
10	1.000	2	2.000	0	+83.552
11	1.000	4	4.000	- 1	- 4.000
12	.997	2	1.994	- 2	- 3.988
13	.990	4	3.960	- 3	-11.880
14	.967	2	1.934	- 4	- 7.736
15	.907	4	3.628	- 5	-18.140
16	.796	2	1.592	- 6	- 9.552
17	.629	4	2.516	- 7	-17.612
18	.416	2	.832	- 8	- 6.656
19	.181	4	.724	- 9	- 6.516
20	.020	1	.020	-10	- .200
		Σf (A)	44.104		-86.280
				Σf (LM)	- 2.728

L = 447.2' S = 22.36' H = 27.15' B = 56.9'

$$C_p = \frac{\sum f(A)}{60} = .735 \quad \text{L.C.B.} = \frac{\sum f(LM) \times S}{\sum f(A)} = 1.38' \text{ Aft } \infty$$

$$\Delta = \frac{S \times \sum f(A) \times A_x}{3 \times 35} = 14,295 \text{ tons}$$

$$\nabla = \Delta \times 35 = 500,325 \text{ cu. ft.}$$

$$C_b = \frac{\nabla}{L B H} = .724$$

$$C_V = \frac{\nabla}{L^3} = 5.58 \times 10^{-3}$$

Total Length	L. ent.	Middle body	L. run
446'	44.1%	9.4%	46.5%

$$C_{pr} = .715 \text{ (existing)}$$

$$C_{pe} = .700 \text{ (calculated)}$$

ALTERATION #4 COEFFICIENTS AND CHARACTERISTICS

STA	A/A _x	SM	f(A)	\bar{y}	f(LM)
0	0	1	0	+10	+ 0
1	.138	4	.552	+ 9	+ 4.968
2	.319	2	.638	+ 8	+ 5.104
3	.529	4	2.116	+ 7	+14.812
4	.730	2	1.460	+ 6	+ 8.760
5	.889	4	3.556	+ 5	+17.780
6	.967	2	1.934	+ 4	+ 7.736
7	.992	4	3.968	+ 3	+11.904
8	.998	2	1.996	+ 2	+ 3.992
9	1.000	4	4.000	+ 1	+ 4.000
10	1.000	2	2.000	0	+79.056
11	1.000	4	4.000	- 1	- 4.000
12	.997	2	1.994	- 2	- 3.988
13	.991	4	3.964	- 3	-11.892
14	.972	2	1.944	- 4	- 7.776
15	.916	4	3.664	- 5	-18.320
16	.808	2	1.616	- 6	- 9.696
17	.642	4	2.568	- 7	-17.976
18	.427	2	.854	- 8	- 6.832
19	.185	4	.740	- 9	- 6.660
20	.020	1	.020	-10	- .200
$\Sigma f(A)$			43.584	$\Sigma f(LM)$	-87.340
					- 8.284

$$L = 457.6' \quad S = 22.88' \quad H = 27.15' \quad B = 56.9'$$

$$C_p = \frac{\Sigma f(A)}{60} = .726 \quad L.C.B. = \frac{\Sigma f(LM)}{\Sigma f(A)} \times S = 4.35' \text{ Aft } \infty$$

$$\Delta = \frac{S \times \Sigma f(A) \times A_x}{3 \times 35} = 14,455 \text{ tons}$$

$$\nabla = \Delta \times 35 = 505,925 \text{ cu. ft.}$$

$$C_b = \frac{\nabla}{L B H} = .716$$

$$C_v = \frac{\nabla}{L^3} = 5.29 \times 10^{-3}$$

Total Length	L. ent.	Middle body	L. run
456'	45.4%	9.2%	45.4%

$$C_{pr} = .715 \text{ (existing)}$$

$$C_{pe} = .684 \text{ (calculated)}$$

APPENDIX E

CONVERSION COEFFICIENTS, EHP, AND SHP DETERMINATION

The calculations in this section are based on the new length of 440' and 20 new stations from the existing AP forward. By using the existing Liberty Ship sectional area curve aft of existing station 3, the sectional areas at the new stations in this region can be determined. For the new bow starting from existing station 3 forward, the sectional areas for the new forward stations are calculated from the new bow form. This was done by Simpson's Rule and checked by planimeter. Thus a revised sectional area curve is determined as illustrated in Fig. 16.

From this revised sectional area curve, the necessary coefficients for EHP determination by Taylor's Standard Series* are obtained and the calculations made. Some of the other coefficients are also included to show the relative changes in the bow and stern due only to the new bow.

The propulsion coefficient, $EHP_{bare} / SHP_{engine} = .78$, as determined in APPENDIX A is used with the EHP_{bare} determined from Taylor's Standard Series to obtain SHP_{engine} . Plots of EHP_{bare} and SHP_{engine} versus speed are illustrated in Fig. 19.

* Reference 13

CONVERSION AREA DETERMINATION

STATIONS

W.L.	S.M.	1/2		1		2		3	
		H.B.	f(A)	H.B.	f(A)	H.B.	f(A)	H.B.	f(A)
0	1/2	0	0	.63	.32	.63	.32	.63	.32
1 1/2'	2	0	0	.92	1.84	3.60	7.2	8.2	16.4
3'	3/2	.25	.38	1.5	2.25	6.50	9.75	11.4	17.1
6'	4	.50	2.00	2.3	9.20	8.00	32.0	14.8	79.2
9'	2	.75	1.50	3.2	6.40	10.00	20.0	17.2	34.4
12'	4	1.25	6.00	4.1	16.40	11.50	46.0	17.8	71.2
15'	2	1.58	3.16	4.8	9.60	12.60	25.2	20.0	40.0
18'	4	2.00	8.00	5.4	21.60	13.70	54.8	20.9	83.6
21'	2	2.40	4.80	6.1	12.20	14.50	29.0	21.6	43.2
24'	4	2.75	11.00	6.6	26.40	15.20	60.8	22.1	88.4
27'	1	3.25	<u>3.25</u>	7.1	<u>7.1</u>	15.80	<u>15.8</u>	22.5	<u>22.5</u>
Summation = A/2		40.09		113.31		300.87		496.32	
Sect. Area, sq. ft = 80.18				226.62		601.74		992.64	
A/A _x = A/1522		.053		.149		.395		.653	
Station		1/2		1		2		3	

DETERMINATION OF COEFFICIENTS

STA	A/A _x	SM	f(A)	\bar{y}	f(LM)
FP	0	1	0	+10	+ 0
1	.149	4	.596	+ 9	+ 5.364
2	.395	2	.790	+ 8	+ 6.320
3	.653	4	2.612	+ 7	+18.284
4	.834	2	1.668	+ 6	+10.008
5	.943	4	3.772	+ 5	+18.860
6	.983	2	1.966	+ 4	+ 7.864
7	.997	4	3.988	+ 3	+11.964
8	.999	2	1.998	+ 2	+ 3.996
9	1.000	4	4.000	+ 1	+ 4.000
10	1.000	2	2.000	0	+86.660
11	.999	4	3.996	- 1	- 3.996
12	.997	2	1.994	- 2	- 3.988
13	.989	4	3.956	- 3	-11.868
14	.963	2	1.926	- 4	- 7.704
15	.900	4	3.600	- 5	-18.000
16	.786	2	1.572	- 6	- 9.432
17	.619	4	2.476	- 7	-17.332
18	.407	2	.814	- 8	- 6.512
19	.177	4	.708	- 9	- 6.372
20	.020	1	.020	-10	- .200
			$\Sigma f(A) = 44.452$		$\Sigma f(LM) = + 1.256$

$$L = 440' \quad S = 22.0' \quad H = 27.15' \quad B = 56.9'$$

$$C_p = \frac{\Sigma f(A)}{60} = .741 \quad L.C.B. = \frac{\Sigma f(LM) \times S}{\Sigma f(A)} = .621' \text{ fwd.}$$

$$\Delta = \frac{S \times \Sigma f(A) \times A_x}{3 \times 35} = 14,175 \text{ tons}$$

$$\nabla = \Delta \times 35 = 496,144 \text{ cu.ft.}$$

$$C_b = \frac{\nabla}{L B H} = .730$$

$$C_v = \frac{\nabla}{L^3} = 5.80 \times 10^{-3}$$

Total Length	L. ent.	Middle body	L. run
440'	43.2%	9.5%	47.3%

$$C_{pr} = .715 \text{ (existing)} \quad C_{pe} = .710 \text{ (calculated)}$$

$$C_{pa} = .735 \quad C_{pf} = .746$$

EHP BY TAYLOR

$$L=440' \quad B/H=2.096 \quad C_v=5.8 \times 10^{-3} \quad R_e=1.318 \times L \times V_k \times 10^5$$

$$C_p=.74 \quad B/H_{\text{corr.}}=\frac{-.154}{.75} \quad \Delta C_f=.004$$

$$C_p=.74$$

$$C_t=C_r+C_f+\Delta C_f$$

V/\sqrt{L}	B/H	$C_r \times 10^{-3}$	$\Delta C_r \times 10^{-3}$	$C_r \times 10^{-3}$	$R_e \times 10^8$	$C_f \times 10^{-3}$	$C_t \times 10^{-3}$
V_k		T.S.S.		conv.			
.75	2.25	1.25	-.041	1.209	9.14	1.548	3.157
15.75	3.00	$\frac{1.45}{.20}$					
.73	2.25	1.13	-.035	1.095	8.90	1.553	3.048
15.33	3.00	$\frac{1.30}{.17}$					
.72	2.25	1.07	-.0329	1.0371	8.78	1.556	2.983
15.11	3.00	$\frac{1.23}{.16}$					
.71	2.25	1.01	-0.0308	.9792	8.65	1.559	2.938
14.90	3.00	$\frac{1.16}{.15}$					
.70	2.25	.96	-.0288	.9312	8.53	1.561	2.892
14.69	3.00	$\frac{1.10}{.14}$					
.69	2.25	.90	-.0308	.8692	8.41	1.564	2.833
14.48	3.00	$\frac{1.05}{.15}$					
.68	2.25	.85	-.0308	.8192	8.27	1.568	2.787
14.25	3.00	$\frac{1.00}{.15}$					
.67	2.25	.80	-.0329	.7671	8.15	1.570	2.737
14.05	3.00	$\frac{.96}{.16}$					
.66	2.25	.78	-.0267	.7533	8.04	1.573	2.726
13.85	3.00	$\frac{.91}{.13}$					
.65	2.25	.73	-.0308	.6992	7.93	1.575	2.674
13.65	3.00	$\frac{.88}{.15}$					
.60	2.25	.60	-.035	.565	7.31	1.592	2.557
12.6	3.00	$\frac{.77}{.17}$					

$EHP = C_t (A) V_k^3$ where
 C_t = total resistance coefficient
 V_k = speed in knots
 A = constant for hull form given by:
 $A = .004280 \rho S$ where:
 ρ = density of sea water = 1.99
 S = wetted surface obtained from T.S.S. by

$$S = C_s \sqrt{\nabla L}$$

For $C_p = .74$ at $B/H = 3.00$ $C_s = 2.581$
 at $B/H = 2.25$ $C_s = 2.567$

Therefor by interpolation for conv.
 at $C_p = .74$ $B/H = 2.096$ $C_s = 2.564$

$$S = 2.564 \sqrt{496,144 \times 440} = 37,800 \text{ ft.}^2$$

$$A = .004380 (1.99) (37,800) = 329$$

V/\sqrt{L}	V_k	V_k^3	C_t	A	EHP_{bare}	SHP_{engine}
.75	15.75	3910	3.157	329	4060	5200
.73	15.33	3600	3.048	329	3610	4620
.72	15.11	3455	2.983	329	3390	4350
.71	14.90	3310	2.938	329	3200	4100
.70	14.69	3170	2.892	329	3020	3870
.69	14.48	3040	2.833	329	2830	3630
.68	14.25	2895	2.787	329	2660	3410
.67	14.05	2775	2.737	329	2500	3200
.66	13.85	2660	2.726	329	2385	3060
.65	13.65	2545	2.674	329	2240	2870
.60	12.6	2001	2.557	329	1680	2150

APPENDIX F

CONVERSION DISPLACEMENT AND OTHER CURVES

In this section 4 stations and 1 half station were used for calculation by Simpson's Rule. For the Liberty Ship existing stations FP, 1/2, 1, 2, and 3 were used to determine the offsets necessary. For the conversion stations marked (FP), (1/2), (1), (2), (3) were used to divide the interval of the new bow into similar stations for calculation on a change basis. Note that the (FP) corresponds to the true FP of the conversion, and that (3) corresponds to the Liberty existing station 3.

In this section the table of offsets used for both Liberty and Conversion are shown, along with the sectional area determination. Calculations for only the 27' waterline are shown for determination of quantities, however all waterlines were calculated in the same manner from the aforementioned data.

LIBERTY SHIP EXISTING

STATIONS W.L.(ft.)	FP Half Breadth	1/2 Half Breadth	1 Half Breadth	2 Half Breadth	3 Half Breadth
0	0	.125	.5	.625	.625
1 1/2	0	.167	1.25	7.0	14.25
3	0	.333	2.25	10.167	17.417
6	0	.75	4.25	13.75	20.75
9	0	1.417	6.333	16.083	22.75
12	0	2.333	8.167	17.916	24.083
15	0	3.417	9.584	19.25	25.00
18	0	4.500	10.834	20.333	25.584
21	0	5.584	12.083	21.083	26.000
24	.333	6.667	13.083	21.75	26.25
27	1.667	7.667	14.00	22.25	26.584

CONVERSION

	(FP)	(1/2)	(1)	(2)	(3)
0	0	0	0	.625	.625
1 1/2	0	0	0	4.916	14.25
3	0	0	0	8.083	17.417
6	0	0	1.916	12.00	20.75
9	0	1.333	5.25	14.667	22.75
12	0	2.0	6.083	16.083	24.083
15	0	2.584	7.083	17.417	25.00
18	0	3.167	8.00	18.417	25.584
21	0	3.584	8.584	19.0	26.00
24	.125	4.00	9.25	19.667	26.25
27	.5	4.417	9.834	20.167	26.584

LIBERTY EXISTING SECTIONAL AREA

STATION		1/2			1		
WL	SM	HB	f(A)	A to WL	HB	f(A)	A to WL
0	1	.125	.125		.5	.5	
3/2	4	.167	.668		1.25	5.00	
3	1	.333	.333		2.25	2.25	
		$\sum f(A) = 1.126$				7.75	
		$A(0-3) = \sum f(A) =$	1.126				7.75
3	1	.333	.333		2.25	2.25	
6	4	.75	3.00		4.25	17.00	
9	1	1.417	1.417		6.333	6.333	
		$\sum f(A) = 4.750$				25.583	
		$A(3-9) = 2 \sum f(A) =$	9.500	10.626		51.166	58.916
9	1	1.417	1.417		6.333	6.333	
12	4	2.333	9.332		8.167	32.668	
15	1	3.417	3.417		9.584	9.584	
		$\sum f(A) = 14.166$				48.585	
		$A(9-15) = 2 \sum f(A) =$	28.332	38.958		97.170	156.086
15	1	3.417	3.417		9.584	9.584	
18	4	4.500	18.000		10.834	43.336	
21	1	5.584	5.584		12.083	12.083	
		$\sum f(A) = 27.001$				65.003	
		$A(15-21) = 2 \sum f(A) =$	54.002	92.960		130.006	286.092
21	1	5.584	5.584		12.083	12.083	
24	4	6.667	26.668		13.083	52.332	
27	1	7.667	7.667		14.000	14.000	
		$\sum f(A) = 39.919$				78.415	
		$A(21-27) = 2 \sum f(A) =$	79.838	172.798		156.830	442.922

LIBERTY EXISTING

STATION			2		3			FP		
WL	SM	HB	f(A)	A to WL	HB	f(A)	A to WL	HB	f(A)	A
0	1	.625	.625		.625	.625		0		
3/2	4	7.00	28.00		14.25	57.00		0		
3	1	10.167	<u>10.167</u>	38.792	17.417	<u>17.417</u>	75.042	0		0
			<u>38.792</u>			<u>75.042</u>				
3	1	10.167	10.167		17.417	17.417		0		
6	4	13.75	55.00		20.75	83.00		0		
9	1	16.083	<u>16.083</u>	201.292	22.75	<u>22.75</u>	321.376	0		0
			<u>81.250</u>			<u>123.167</u>				
9	1	16.083	16.083		22.75	22.75		0		
12	4	17.916	71.664		24.083	96.332		0		
15	1	19.25	<u>19.25</u>	415.286	25.00	<u>25.00</u>	609.540	0		0
			<u>106.997</u>			<u>144.082</u>				
15	1	19.25	19.25		25.00	25.00		0		
18	4	20.33	81.320		25.584	102.336		0		
21	1	21.083	<u>21.083</u>	658.592	26.00	<u>26.00</u>	916.212	0		0
			<u>121.653</u>			<u>153.336</u>				
21	1	21.083	21.083		26.00	26.00		0		
24	4	21.75	87.00		26.25	105.00		.333	1.332	
27	1	22.25	<u>22.25</u>	919.258	26.584	<u>26.584</u>	1231.380	1.667	<u>1.667</u>	5.998
			<u>130.333</u>			<u>157.584</u>			<u>2.999</u>	

CONVERSION

STATION

(FP)

(1/2)

WL	SM	HB	f(A)	A to WL	HB	f(A)	A to WL
0 to 3	1	0	0	0	0	0	0
3	1	0	0		0	0	
6	4	0	0		0	0	
9	1	0	0		1.333	<u>1.333</u> 1.333	2.666
9	1	0	0		1.333	1.333	
12	4	0	0		2.0	8.00	
15	1	0	0		2.584	<u>2.584</u> 11.917	26.500
15	1	0	0		2.584	2.584	
18	4	0	0		3.167	12.668	
21	1	0	0		3.584	<u>3.584</u> 18.836	64.172
21	1	0	0		3.584	3.584	
24	4	.125	.5		4.00	16.00	
27	1	.5	<u>.5</u> 1.0	2.0	4.417	<u>4.417</u> 24.001	112.174

CONVERSION

STATION			(1)		(2)		
WL	SM	HB	f(A)	A to WL	HB	f(A)	A to WL
0	1	0	0		.625	.625	
3/2	4	0	0		4.916	19.664	
3	1	0	0	0	8.083	<u>8.083</u>	28.372
						<u>28.372</u>	
3	1	0	0		8.083	8.083	
6	4	1.916	7.664		12.00	48.00	
9	1	5.25	<u>5.25</u>	25.828	14.667	<u>14.667</u>	169.872
			<u>12.914</u>			<u>70.750</u>	
9	1	5.25	5.25		14.667	14.667	
12	4	6.083	24.332		16.083	64.332	
15	1	7.083	<u>7.083</u>	99.158	17.417	<u>17.417</u>	362.704
			<u>36.665</u>			<u>96.416</u>	
15	1	7.083	7.083		17.417	17.417	
18	4	8.00	32.00		18.417	73.668	
21	1	8.584	<u>8.584</u>	194.492	19.0	<u>19.0</u>	582.874
			<u>47.667</u>			<u>110.085</u>	
21	1	8.584	8.584		19.0	19.0	
24	4	9.25	37.00		19.667	78.668	
27	1	9.834	<u>9.834</u>	305.328	20.167	<u>20.167</u>	818.544
			<u>55.418</u>			<u>117.835</u>	

STATION (3) is identically station 3 of Liberty Ship so these calculations are not repeated here.

DISPLACEMENT AND L.C.B. CALCULATION

LIBERTY EXISTING

STA	SA to 27'	SM	f(A)	lever	f(LM)
FP	5.998	1/2	2.999	+10	+ 29.990
1/2	172.798	2	345.596	+ 9.5	+ 3283.162
1	442.922	3/2	664.383	+ 9.0	+ 5979.447
2	919.258	4	3677.032	+ 8	+29416.256
3	1231.380	1	1231.380	+ 7	+ 8619.660
S = 20.8' $\delta f(A) = \frac{5921.390}{}$ $\delta f(LM) = \frac{+47328.515}{}$					

$$S/3 \times 1/35 \times \delta f(A) = \Delta_3 \text{ fwd} = 1173 \text{ tons}$$

$$\begin{aligned} \text{from disp. curve} \quad \Delta_{\text{exist.}} &= 13820 \text{ tons} \\ \Delta_3 \text{ aft} &= 12647 \text{ tons} \end{aligned}$$

$$L.C.B. = 8.73' \text{ fwd. } \nabla_{\text{exist.}} = 483,700 \text{ cu. ft.}$$

$$LM_{\text{existing}} = 4,223,000 \text{ ft.}^4 \text{ from L.C.B.} = LM/\nabla$$

$$\delta LM = S^2/3 \times \delta f(LM) = 6,786,000 \text{ ft.}^4$$

$$LM_3 \text{ aft} = LM_{\text{existing}} - \delta LM = - 2,563,000 \text{ ft.}^4$$

CONVERSION

STA	SA to 27'	SM	f(A)	lever to 3	LM
(FP)	2.0	1/2	1.0	+ 3.0	3.0
(1/2)	112.174	2	224.348	+ 2.5	560.87
(1)	305.328	3/2	457.988	+ 2.0	915.976
(2)	818.544	4	3274.176	+ 1.0	3274.176
(3)	1231.380	1	1231.380	0	0
$\delta f(A) = \frac{5188.892}{}$ $\delta f(LM) = \frac{+4755.222}{}$					

$$S=28.8'$$

$$\begin{aligned} \Delta_3 \text{ fwd conv.} &= 1423 \text{ tons} & C.G. 3 \text{ fwd. c} &= \frac{S \times \delta f(LM)}{\delta f(A)} \\ \Delta_3 \text{ aft} &= 12647 \text{ tons} & C.G. 3 \text{ fwd. c} &= 26.40 \text{ ft.} \\ \Delta_{\text{conv.}} &= 14070 \text{ tons} \end{aligned}$$

$$\delta \nabla = 35 \times \Delta_3 \text{ fwd. conv.} = 49,800 \text{ cu. ft.}$$

DISPLACEMENT AND L.C.B. CALCULATION (CONT'D)

$$\Delta LM = \Delta \nabla (L_3 \text{ to } x + L_{c.g.} \text{ of } 3 \text{ fwd.c})$$

$$= 49,800 (145.6' + 26.40') = + 8,566,000$$

$$LM \text{ 3 aft} = \underline{- 2,563,000}$$

$$LM \text{ of conversion with new bow} = + 6,003,000 \text{ ft}^4$$

$$LCB = LM/\nabla = +6,003,000/(35 \times \Delta_{\text{conv.}})$$

$$= 6,003,000/492,700$$

$$L.C.B. \text{ conversion} = 12.18' \text{ fwd of existing } \otimes$$

CALCULATION OF OTHER CURVES

LIBERTY EXISTING 27' WL S = 20.8'

STA	HB	SM	f(A)	lever	f(LM)	HB ³	HB ³ (SM)
FP	1.667	1/2	.834	3	2.502	4.632	2.316
1/2	7.667	2	15.334	2.5	38.335	450.688	901.376
1	14.000	3/2	21.00	2	42.00	2744.00	4116.00
2	22.25	4	89.00	1	89.00	11015.14	44060.56
3	26.584	1	26.584	0	0	18787.15	18787.154
$\Sigma f(A) = 152.752$							$\Sigma f(I_t) = 67867.406$
					$\Sigma f(LM) = 171.837$		

CONVERSION 27' WL S = 28.8'

STA	HB	SM	f(A)	lever	f(LM)	HB ³	HB ³ (SM)
(FP)	.5	1/2	.25	3	.75	.125	.063
(1/2)	4.417	2	8.834	2.5	22.085	86.175	172.350
(1)	9.834	3/2	14.751	2	29.502	951.022	1426.533
(2)	20.167	4	80.668	1	80.668	8202.078	32808.312
(3)	26.584	1	26.584	0	0	18787.154	18787.154
$\Sigma f(A) = 131.087$							$\Sigma f(I_t) = 53194.412$
					$\Sigma f(LM) = 133.005$		

DATA FROM LIBERTY DISPLACEMENT AND OTHER CURVES NECESSARY

$$\nabla_e = 483,700 \text{ ft.}^3 \quad TPI_e = 48.46 \quad C.F._e = 2.44' \text{ Fwd.} \quad KM_{t_e} = 24.20'$$

$$MT \ 1_e'' = 1317 \text{ ft.-tons} \quad KB_e = 14.34' \quad L_e = 416'$$

DATA FOR CONVERSION PREVIOUSLY CALCULATED

$$L_c = 440' \quad \nabla_c = 492,700 \quad KB_c = 14.34'$$

NOTE: Subscript e for Liberty, and subscript c for conversion in calculations to follow.

To find Tons per inch immersion, TPI from:

$$TPI = A_{wl} / (12 \times 35) = A_{wl} / 420 \quad \text{and}$$

$$A_{wl_c} = A_{wl_e} - A_{wl}(3fwd)_e + A_{wl}(3fwd)_c$$

$$A_{wl_e} = TPI \times 420 = 48.68 \times 420 = \quad + 20,353 \text{ sq.ft.}$$

$$A_{wl}(3fwd)_e = S/3 \times \sum f(A) =$$

$$\quad \quad \quad 20.8/3 \times 152.752 =$$

$$\quad \quad \quad 6.93 \times 152.752 = \quad - 1,059 \text{ sq.ft.}$$

$$A_{wl}(3fwd)_c = 28.8/3 \times 131.087 =$$

$$\quad \quad \quad 9.6 \times 131.087 = \quad + 1,258 \text{ sq.ft.}$$

$$A_{wl_c} = \dots \dots \dots 20,552 \text{ sq.ft.}$$

$$TPI_c = A_{wl_c} / 420 = 20,552 / 420 = \underline{\underline{48.93}} = TPI_c$$

To find center of flotation of waterline, CF, use:

$$CF = \text{Longitudinal moment of waterline area/area}$$

$$= LM_x / A_{wl}$$

$$LM_{x_c} = LM_{x_e} - LM_x(3fwd)_e + LM_x(3fwd)_c \quad \text{and}$$

$$LM_x(3fwd) = A_{wl}(3fwd) \times [L_x \text{ to } 3 + L_{c.g.}(3fwd)] \quad \text{where}$$

$$L_{c.g.}(3fwd) = S \times \sum f(LM) / \sum f(A)$$

$$L_{c.g.}(3fwd)_e = 20.8 \times 171.837 / 152.752$$

$$= 23.40' \text{ fwd of } 3$$

$$L_{c.g.}(3fwd)_c = 28.8 \times 131.005 / 131.087$$

$$= 29.22' \text{ fwd of } 3$$

$$LM_{x_e} = A_{wl_e} \times CF_e = 20,353 \times 2.44 = \dots + 49,661 \text{ ft.}^3$$

$$LM_x(3fwd)_e = 1,059 \times (145.6 + 23.40)$$

$$= 1,059 \times 169.0 = \dots -178,984 \text{ ft.}^3$$

$$LM_x(3fwd)_c = 1,258 \times (145.6 + 29.22)$$

$$= 1,258 \times 174.82 = \dots +220,000 \text{ ft.}^3$$

$$LM_{x_c} = \dots \dots \dots + 90,677 \text{ ft.}^3$$

$$CF_c = LM_{x_c} / A_{wl_c} = (+90,677) / 20,552 = \underline{\underline{4.41' \text{ fwd.}}} = CF_c$$

To find Moment to Trim 1", MTI, use:

$$MTI = I_1 / (L \times 420)$$

$$I_1 = I_x - A_{wl} (CF)^2 \quad \text{and}$$

$$I_{1c} = I_{1e} + A_{wl_e} (CF_e)^2 - A_{wl(3fwd)_e} \left[L_x \text{ to } 3 + L_{c.g.}(3fwd)_e \right]^2 \\ + A_{wl(3fwd)_c} \left[L_x \text{ to } 3 \times L_{c.g.}(3fwd)_c \right]^2 \\ - A_{wl_c} (CF_c)^2 \quad \text{where everything except } I_1 \text{ as determined before.}$$

$$I_{1e} = MTI_e \times L_e \times 420 = (1317)(416)(420) = +230,382,000 \text{ ft.}^4$$

$$A_{wl_e} (CF_e)^2 = 20,353 \times (2.44)^2 = + 121,000 \text{ ft.}^4$$

$$A_{wl(3fwd)_e} \left[L_x \text{ to } 3 + L_{c.g.}(3fwd)_e \right]^2 = \\ 1,059 \times (169.0)^2 = . . - 30,248,000 \text{ ft.}^4$$

$$A_{wl(3fwd)_c} \left[L_x \text{ to } 3 + L_{c.g.}(3fwd)_c \right]^2 = \\ 1,258 \times (174.82)^2 = + 38,460,000 \text{ ft.}^4$$

$$A_{wl_c} (CF_c)^2 = 20,552 \times (4.41)^2 = - \underline{399,000 \text{ ft.}^4}$$

$$I_{1c} = 238,316,000 \text{ ft.}^4$$

$$MTI_c = I_{1c} / L_c \times 420 = 238,316,000 / (440 \times 420) =$$

$$\underline{\underline{1290 \text{ ft.-tons} = MTI_c}}$$

To find Transverse Metacenter above base, KM_t , use:

$$BM_t = KM_t - KB$$

$$BM_t = I_t / \nabla \quad \text{and}$$

$$I_{t_c} = I_{t_e} - I_{t(3fwd)_e} + I_{t(3fwd)_c} \quad \text{where}$$

$$I_{t(3fwd)} = 2/9 \times S \times \sum f(I_t)$$

$$BM_{t_e} = KM_{t_e} - KB_{t_e} = 24.20 - 14.34 = 9.86 \text{ ft.}$$

$$I_{t_e} = BM_{t_e} \times \nabla_e = 9.86 \times 483,700 = . . . +4,769,000 \text{ ft.}^4$$

$$I_{t(3fwd)_e} = 2/9 \times 20.8 \times 67,867 = - 313,000 \text{ ft.}^4$$

$$I_{t(3fwd)_c} = 2/9 \times 28.8 \times 53,194 = + \underline{340,000 \text{ ft.}^4}$$

$$I_{t_c} = 4,796,000 \text{ ft.}^4$$

$$BM_{t_c} = I_{t_c} / \nabla_c = 4,796,000 / 492,700 = 9.73 \text{ ft.}$$

$$\text{Calculations proved } KB_c = KB_e = . . . \underline{14.34 \text{ ft.}}$$

$$KM_{t_c} = KB_c + BM_{t_c} = \underline{\underline{24.07' = KM_{t_c}}}$$

APPENDIX G

FLOODABLE LENGTH

Approximation of Floodable Length curve is based upon Webster's Method.*

Depth to Margin Line = 37.0 ft.

Molded draft = 27.0 ft.

Freeboard = 10 ft.

Block coefficient = 0.730

Freeboard Ratio, f , = freeboard/depth = $10/37 = 0.27$

Sheer forward = 17 ft.

Sheer ratio, fwd. = sheer/depth = $17/37 = 0.46$

Sheer aft = 6 ft.

Sheer ratio aft = sheer/depth = $6/37 = 0.161$

Permability assumed, $\mu = 0.64$ at ends;
 $\mu = 0.80$ machinery spaces

STATIONS % L	$m_{corr.}$	$a_{corr.}$	$a + f$	% Flood. Length	
				mach. space $m(a + f)$	ends $.80\mu [m(a+f)]$
AFT TERM.	40.15	.2213	.4913	19.75	24.7
15	53.28	.0485	.3185	17.00	21.2
20	53.08	.0408	.3108	16.50	20.6
30	63.25	.0415	.3515	22.20	27.8
40	91.94	.0147	.2847	26.20	32.8
45	105.51	.0013	.2687	28.30	36.0
50	104.90	.0036	.2736	28.65	35.3
60	85.01	.0302	.3002	25.50	31.9
70	62.15	.0652	.3352	20.80	26.0
80	59.02	.0720	.3420	20.20	25.2
85	62.91	.0936	.3663	23.10	28.9
FWD TERM.	41.66	.3340	.6040	25.20	31.5

* Reference 23 p. 22

APPENDIX H

HULL STRENGTH CONSIDERATIONS

Since the length of the Liberty has been increased to 440 feet, a check on the longitudinal strength is necessary.

Using the drawing, Fig. 21, Midship section of Liberty ships, which is taken from "Marine Engineering and Shipping Review", April, 1942 an approximation to the section modulus is calculated.* The assumed neutral axis for the calculation is the base line of the ship. Those parts which were chosen to provide the strength are as indicated in the calculation. The following notation is used:

a = area, square inches.

d_n = distance of the center of gravity of each component above the base line, feet.

$a d_n$ = moment of area of each component about the base line inches squared x feet.

$a (d_n)^2$ = product of the moment of area of each component times its distance from the baseline, inches²xfeet².

i_o = moment of inertia of area of each component about its own center of gravity, inches²x feet².

d_g = distance of the neutral axis above the base line, ft.

For simplification, small moments of inertia have been neglected; also in some cases the center of gravity of some of the components has been approximated.

I = total moment of inertia of midship section, inches²ft²?

c = distance from neutral axis to main deck at side or base line as indicated, feet.

* Reference 14, p. 213

MEMBER	SCANTLING	a	d _n	a d _n	a d _n ²	10
Center Girder (1/2 only)	43.5x0.54 2	11.75	1.825	21.45	39.10	12.8
Keel Plate	30 x 0.88	26.4	0.1	2.64	0.26	
Dble.Bott. CL Strake	30 x 0.58	17.4	3.63	63.2	230.0	
Girder	40 x 0.42 (mean)	16.8	1.75	29.4	51.4	15.6
Dble.Bott. PL.#1	80 x 0.44 (least)	35.2	3.63	128.0	464.0	
Dble.Bott. PL.#2	80 x 0.44	35.2	3.63	128.0	464.0	
Dble.Bott. PL.#3	80 x 0.44	35.2	3.63	128.0	464.0	
Margin PL.	66 x 0.54 (least)	35.6	3.63	129.0	469.0	
Gusset PL.	12 x 0.44	5.3	5.0	26.4	132.0	0.3
A Strake	88 x 0.64	56.4	0	-	-	
B Strake	88 x 0.64	56.4	0.16	9.02	1.4	
C Strake	88 x 0.64	56.4	0.33	18.6	6.1	
D Strake (5' Rad.)	88 x 0.64	56.4	3.0	169.0	506.0	138
E Strake	64.5x0.63	40.6	8.5	345.0	2940.0	98
F Strake	80 x 0.63	50.4	14.5	730.0	10600.0	187
G Strake	80 x 0.63	50.4	21.0	1060.0	22200.0	187
H Strake	80 x 0.63	50.4	27.75	1397.0	38700.0	187
J Strake	80 x 0.70	56.0	37.5	2100.0	78800.0	208
Upper Dk. Girder	18 x .625	11.25	37.5	422.0	15830.0	2
2nd Deck Stringer	54 x 0.40	21.6	28.6	618.0	17700.0	
2nd Deck PL.#2	84 x 0.40	33.6	28.6	961.0	27500.0	
2nd Deck PL.#1	84 x 0.40	33.6	28.6	961.0	27500.0	
Upper Deck Stringer	57 x 0.71	40.5	38.1	1540.0	58600.0	
Upper Deck PL.#2	82 x 0.71	58.2	38.1	2220.0	84500.0	
Upper Deck PL.#1	82 x 0.71	58.2	38.1	2220.0	84500.0	
SUMMATION		949.2		15426.7	472197.26	1035.7

$$d_g = \frac{\sum a \quad dn}{\sum a} = \frac{15400}{949} = 16.2 \text{ ft. above baseline}$$

$$\sum a d_g^2 = 949 \times (16.2)^2 = 249,000 \text{ inches}^2 \times \text{feet}^2$$

$$I/2 = 473,000 - 249,000 = 224,000 \text{ inches}^2 \times \text{feet}^2$$

$$I_{\text{total}} = 448,000 \text{ inches}^2 \times \text{feet}^2$$

$$\text{Top } c = 21'1''$$

$$\text{Bottom } c = 16'3''$$

$$\text{Top } I/c = \frac{448,000}{21.08}$$

$$= 21,300 \text{ in}^2 \times \text{ft.}$$

$$\text{Bottom } I/c = \frac{448,000}{16.2}$$

$$= 27,700 \text{ in}^2 \times \text{ft.}$$

The required longitudinal modulus for effective material* where L is less than 600 feet and Beam, B, is between $L/10 + 5 = 49$ and $L/10 + 20 = 64$ is given as;

$f \times d \times B$ where

f = factor obtained from table

d = draft, feet

B = molded breadth in feet, amidships

$$I/c \text{ required} = f \times d \times B = 13.10 \times 27.15 \times 56.9 = 20,200 \text{ in}^2 \text{ ft.}$$

The Bending Moment, M, using the standard bending moment formula is as follows:

$$M = \frac{0.75 L^2 \times B \times d}{(35)^2} = \frac{0.75 \times (440)^2 \times 56.9 \times 27.15}{(35)^2}$$

$$M = 183,000 \text{ ft.-tons}$$

The stress using this standard bending moment would be:

$$\sigma = \frac{0.75 L^2}{(35)^2 \times f} = \frac{0.75 (440)^2}{(35)^2 \times 13.1} = 9.05 \text{ tons/in}^2.$$

* Reverence 10, p. 16

By using the standard bending moment and the section moduli as approximated, the stresses at top and bottom of the section would be:

$$\sigma_{\text{top}} = \frac{M}{I/c_{\text{top}}} = \frac{183,000}{21,300} = 8.6 \text{ tons/in}^2$$

$$\sigma_{\text{bottom}} = \frac{M}{I/c_{\text{bottom}}} = \frac{183,000}{27,700} = 6.6 \text{ tons/in}^2$$

It is known that there is an approved American Bureau of Shipping alteration employing riveted butt straps on the decks of the Liberty Ships for crack arrestors. Since information could not be obtained concerning the size, number, and location of these butt straps; no attempt was made to correct the strength calculation for their inclusion.

APPENDIX I

WEIGHT ADDITIONS

HULL WEIGHTS NEW BOW

An approximate estimate of the weight of new bow added over the existing bow is determined on the basis that an average frame such as that existing at frame #22 would be typical of the average size frame in the new added length of 24 feet of bow. A more exact method for determining the weight added does not seem warranted for this type of investigation.

The calculations for this addition are shown on the following page, and amount to 60 tons weight addition.

PROPELLERS AND SHAFTING

The existing propeller and shafting weight is 61 tons; 10.5 tons for propeller and 50.5 tons for shafting. Based upon these figures, the new propeller weight was estimated at 24,000 lbs. or 10.7 tons. For the shafting the ratio of the old and new diameters squared was used to estimate the new shafting weight; i.e.

$$(D_{\text{new}} / D_{\text{old}})^2 \times \text{Wt.}_{\text{old}} = \text{Wt.}_{\text{new}} = (15.25/13.5)^2 \times 50.5$$

$$\text{Weight of new shafting} = 64.5 \text{ tons}$$

Therefor the new propeller and shafting weight equals 10.7 tons plus 64.5 tons or approximately 75 tons, representing a weight addition of 14 tons.

HULL WEIGHT ESTIMATION from typical Frame #22, *frame
spacing 27 inches

ITEM	Total est. length or area per frame.	Est. wt. in lbs. per frame space.
------	---	--------------------------------------

TRANSVERSE MEMBERS

7 x 4 x 15.8# Inv. L	34 ft.	537
8 x 4 x 17.2# Inv. L	30 ft	516
DET. 7-A 13#	2 sq. ft.	25
DET. 7-B 15.5#	12 sq. ft.	180
DET. 7-D 17.9#	12 sq. ft.	215
8 x 3.5 x 3.5 x 21.4# [	28 ft.	600
10 x 3.5 x 3.5 x 23.6# [	56 ft.	1320

LONGITUDINAL MEMBERS

	Width, ft.		
Inner bottom 21.2#	16 ft.	36 sq. ft.	764
Inner bottom 25.3#	10 ft.	22.5 sq. ft.	568
Shell 28.6#	18 ft.	40.5 sq. ft.	1158
Shell 26.1#	6 ft.	13.5 sq. ft.	352
Shell 23.7#	36 ft.	81.0 sq. ft.	1920
Keel 35.9#	1 ft.	2.25 sq. ft.	81
2nd Dk. 16.3#	27 ft.	60.8 sq. ft.	990
Upper Dk. 21.2#	30 ft.	67.5 sq. ft.	1430
TANK TOP 21.2#	42 ft.	94.5 sq. ft.	2000
	Total		12656 lbs.

Approximate weight of hull steel added in tons for 24 ft.
additional bow is given by:

Length added x weight of frame per ft. =

$$24 \times (12/27) \times (12656/2240) = 60 \text{ tons}$$

*

Reference 9, Framing Sections 13 to 165

REDUCTION GEAR WEIGHT

The weight of gears was determined before in APPENDIX C, Reduction gear design. These weights are repeated here and approximations made for other components to estimate complete weight.

Weight of gears only:	8755 lbs.
	8755 lbs.
	7710 lbs.
Casing and sump	1000 lbs. (assumed)
Total	26220 lbs. or 26,500 lbs. est.

26,500 lbs. = 11.8 tons; therefor assume

Reduction Gear Weight = 12 tons

MACHINERY ADDITIONS

For all machinery additions either known weights were doubled, or estimates were made for determining the new total machinery weights.

FINAL TABULATION OF WEIGHT ADDITIONS TO FIND LIGHT SHIP WT.

Item #	Description	Liberty	Wt. Added	Conversion
0 - 6	Hull Steel	1981	60	2041
7	Foundations	50	35	85
8	Deck Houses	139		139
9	Rivet & Weld	60	7	67
Sub-total	STEEL	2230		2332
10 - 19	OUTFIT	710	14	724
20	Prop. Units	140	140	280
	+ Red. Gr.		12	12
21	Main Feed System	10	10	20
22	Make up feed, evap.	2		2
23	Shafting & Prop.	61	14	75
24	Lube oil system	2	1	3
25	Compressed air sys.	0		0
26	Boilers	130	130	260
27	Steam piping	15	10	25
28	Misc.	45		45
29	Liquids	45	45	90
Sub-total	MACHINERY	450		812
Total	LIGHT SHIP	3390	478	3868

APPENDIX J

CAPACITY CHANGES

In this section the following methods of calculation were used:

1. In vicinity of Hold #1 the area curves for capacity changes, Fig. 20, were integrated by planimeter between levels and bulkheads where shown to obtain the molded volumes of spaces.

2. For Hold #3 and vicinity, since this is in the region of wall sided structure, a ratio of old length to new length was applied to existing volumes to obtain the new capacities.

3. For Deep Tank #3 the volume lost was calculated on the basis of the difference in volume of the enlarged thrust recess for the reduction gear and the former thrust recess volume.; i.e.

Thrust Recess (old) 8' wide x 10'3" long x 11'4" deep
equals 930 cu. ft.

Enlarged Thrust recess for reduction gears:
10' long x 33'6" wide by 16'6" deep equals
5540 cu. ft.

Volume lost by enlargement = $5540 - 930 = 4610$ cu. ft.

CAPACITY CHANGES FUEL OIL

LIBERTY EXISTING SPACE	cu. ft.	gals.	TONS at 37.23 $\frac{ft^3}{ton}$
F.O. TANK #1, (D.B.)	4914	36,863	132
F.O. SETT. Fr.88-96P	1898	14,083	51
F.O. SETT. Fr.88-96S	1898	14,083	51
Deep Tank #3 P&S	26100	195,028	<u>700</u>
	Sub-total existing fuel		934 tons

CONVERSION

SPACE	Molded Volume	Avail. Volume at %	gals.	TONS
F.O. TANK #1 (D.B.)	7400	6290 at 85%	47,100	169
F.O. SETT. Fr.81-90P	2207	2135 at 97%	16,000	57
F.O. SETT. Fr.86-96S	2450	2370 at 97%	17,800	64
DEEP TANK #1 P&S	11900	10700 at 90%	80,200	288
DEEP TANK #2 P&S	15500	13950 at 90%	104,500	375
DEEP TANK #3 P&S	26323	22900 at 87%	171,500	<u>615</u>
	Sub-total conversion fuel			1568 tons

Conversion Sub-total = 1568 Tons
 Liberty Sub-total. = 934 Tons
 Net gain fuel oil capacity . . . = 634 Tons
 Liberty existing capacity(Total) = 1819 Tons
 Total Conversion fuel oil cap. = 2453 Tons

CAPACITY CHANGES - CARGO

LIBERTY EXISTING

SPACE	Grain cubic	Bale cubic
Hold #1	41,257	36,083
Tween Deck #1	42,924	39,322
Hold #3 (20 Frames)	68,459	59,793
Tween Deck #3 (20 Fr.)	27,970	23,904
Deep Tank #1 P&S	7,278	5,733
Deep Tank #2 P&S	14,946	10,862
Deep Tank #3 P&S	<u>26,862</u>	<u>24,530</u>
Sub-totals existing	229,696 gr.	200,227 bale

CONVERSION

SPACE	Molded Volume	Grain at %	Bale at %
Hold #1	48,250	45,800 at 95%	42,000 at 87%
Tween Deck #1	59,650	56,600 at 95%	51,900 at 87%
Hold #3 (13 Frames)		45,600	38,900
Tw. Deck #3 (13 Frames)		18,180	15,550
Deep Tank #1 P&S	11,900	11,300 at 95%	10,350 at 87%
Deep Tank #2 P&S	15,500	14,750 at 95%	13,500 at 87%
Deep Tank #3 P&S	26,323	<u>25,000 at 95%</u>	<u>22,900 at 87%</u>
Sub-totals conversion		217,230 gr.	195,100 bale
Conversion Sub-totals		217,230 grain	195,100 bale
Liberty Sub-totals		<u>229,696 grain</u>	<u>200,227 bale</u>
Net loss in capacity		12,466 grain	5,127 bale
Liberty existing capacity (total)		<u>562,608 grain</u>	<u>499,573 bale</u>
Total capacity Conversion		550,142 grain	494,446 bale

APPENDIX K

FUEL OIL CONSUMPTION AND RELATED TOPICS

STACK AREA CALCULATION

The fuel oil rate for one unit at 2300 SHP is approximately 230 barrels per day.* To convert to pounds of fuel oil per hour:

$230 \text{ barrels/day} \times 1 \text{ day}/24 \text{ hrs.} \times 31.5 \text{ gals/barrel} \times 8.06 \text{ pounds/gal.} = 2430 \text{ pounds per hour per unit.}$

Thus the total fuel oil burned for 4600 SHP (two units) is 4860 pounds per hour. Based upon 200 pounds of fuel per hour per square foot of stack area** the required stack area is:

$4860 \text{ pounds/hr.} \times 1/200 \text{ sq. ft. per pound per hr.}$
equals 24.3 square feet required stack area.

Present inner stack Diameter is 5.5' giving a presently installed stack area of 23.8 square feet.

We will accept the present stack area as sufficient since the required stack area would entail an enlargement of the inner stack diameter by only .05'

* Reference 26

**Reference 12, p. 95

RANGE

The range will be calculated at the full power speed of 15.3 knots using 4600 SHP. As before the fuel oil rate at this power is 4860 pounds per hour. Therefor:

$$\text{Range} = 2453 \text{ tons fuel} \times 2240 \text{ \#/ton} \times 1/4860 \text{ \#/hr.} \\ \times 15.3 \text{ knots}$$

$$\text{Range} = 17,500 \text{ miles}$$

FUEL OIL CONSUMPTION PER MILE

The fuel oil consumption per mile at 15.3 knots is given by:

$$460 \text{ bbl./day} \times 1/24 \text{ hr./day} \times 1/15.3 \text{ mile} = \\ 1.25 \text{ bbl./mile at 15.3 knots for 4600 SHP}$$

Fuel oil consumption at other speeds and powers will be listed below:

15 knots at 4200 SHP using 420 barrels per day;
consumption = 1.17 bbl./mile

14.5 knots at 3600 SHP using 360 barrels per day;
consumption = 1.04 bbl./mile

For the existing ship the fuel oil consumption at 12.2 knots with 2300 SHP using 230 barrels per day is .785 barrels per mile. For this same fuel consumption per mile, the conversion would be making approximately 13 knots with 2400 SHP using 240 barrels per day; thus the decreased resistance of the new hull form is illustrated.

APPENDIX L

FREEBOARD AND TRIM

LOAD LINE CALCULATION

The basic minimum freeboard* for L=440 ft. = 84 inches

Addition for flush deck steamer $(1.5 \times 440/100)$
 $\frac{= 6.6''}{90.6''}$

The coefficient of fineness is given by:

$$C = \frac{35 \times \Delta}{L \times B \times d_1}, \text{ where}$$

Δ = vessel's molded displacement in tons
(excluding bossing) at a mean molded
draft d_1

$$d_1 = 85\% \text{ of molded depth} = .85 \times 37.33' = 31.7'$$

$$B = \text{maximum breadth amidships, molded} = 56.9'$$

$$C = \frac{35 \times 16,800}{440 \times 56.9 \times 31.7} = 0.742$$

Correction for coefficient of fineness:

$$\frac{0.742 + 0.68}{1.36} = \frac{1.422}{1.36} = 1.045$$

$$\text{Therefor freeboard corrected} = 1.045 \times 90.6 = 94.6 \text{ inches}$$

$$L/15 = 440/15 = 29.4' < D = 37.33' \text{ depth}$$

Deduction for excessive depth:

$$(D - L/15) \times R \text{ where } R = 3$$

$$(37.33 - 29.4) \times 3 = 23.8 \text{ inches}$$

Final freeboard as computed by rules (required) = 70.8"

Freeboard of Conversion at 27.15' DLWL = 122.2"

* Reference 10, p. 23

If the converted Liberties are operated at a full load draft of 27.15 feet, they will be well within the freeboard limitations as required by law. The draft must be limited to 27.15 feet due to strength considerations. (See APPENDIX H)

TRIM

An approximation for determining the trim of the conversion will be made based on the light ballast condition of the PATRICK HENRY*. Data used from these trials of the PATRICK HENRY follows:

TANKAGE CONDITION

Fore peak - empty

Deep tanks forward - empty

Double bottom tanks - fuel oil and fresh water

After deep tanks - fresh water

After peak tank - fresh water

DRAFT Forward 7'3"
 Aft 17'4"
 Mean 12'3 1/2"

DISPLACEMENT from curves = 5700 tons
Trim corr. (10') = -130 tons
Sp. gr. corr. - 80 tons
Corr. displacement 5490 tons

To find center of gravity of ship in light ballast condition:

Enter displacement = 5490 tons (Fig. 14)

Mean draft = 12'

C.F. = 10.6' fwd. Ø

MT 1" = 962 ft. tons

Trim - 10'1" = 121"

L.C.B. = 10.86' fwd. Ø

* Reference 24

$$\begin{aligned}\text{Trimming moment} &= \text{Trim} \times \text{MT } 1'' = 121'' \times 962 \text{ ft.-tons/in.} \\ &= 116,402 \text{ ft.-tons}\end{aligned}$$

$$\text{Trimming moment} = \Delta (\text{L.C.G.} - \text{L.C.B.}) = \Delta \times \text{Arm}$$

$$\text{Therefore Arm} = 116,402/5490 = 21.25'$$

$$\text{L.C.G.} = 21.25' - \text{L.C.B. (fwd)} = 21.25' - 10.86'$$

$$\text{L.C.G.} = 10.39' \text{ aft } \otimes$$

For the conversion the change in moments and weights due to structure and machinery are based on the following table.

ITEM	Weight added	Dist. from \otimes	Moment
Hull	60 tons	+214 ft.	+12,840
Boilers	130 tons	+ 9.5 ft.	+ 1,235
Main Eng.	140 tons	- 35.5 ft.	- 4,970
Shafting	14 tons	-127 ft.	- 1,780
Red. Gr.	12 tons	- 51.25 ft.	- 615
Misc.	122 tons	+ 20 ft.	+ 2,440
Totals	<u>+478 tons</u>		<u>+ 9,150</u> ft.-tons

To find the new L.C.G. of conversion and displacement at the light ballast condition:

ITEM	Weight	Arm	Moment
Existing Liberty	5490	- 10.39	-57,041
Structure changes	478		+ 9,150
F.O.#1 Double Bott.	37 (added)	+162	+ 6,000
Totals	<u>6005 tons</u>		<u>-41,891</u> ft.-tons

$$\begin{aligned}\text{L.C.G. of conversion} &= \text{Moment} / \text{weight} \\ &= - 41,891/6005 = 6.97' \text{ aft } \otimes\end{aligned}$$

For conversion:

Enter displacement = 6005 tons (Fig.14)

Mean draft = 12.75' = 12' 9"

L.C.B. = 13.3' fwd of ~~æ~~

MT 1" = 960 ft. tons

Trimming moment = Δ (L.C.G. - L.C.B.)

= 6005 (-6.97 - 13.3) = 6005 (-20.27)

= -121,500 ft.-tons

Trim = Trimming moment / MT 1"

= -121,500 / 960 = 126" = 10' 6" trim by stern

New drafts are approximately:

Draft aft = Mean draft + Trim/2

= 12' 9" + 5' 3" = 18' 0"

Draft fwd. = Mean draft - Trim/2

= 12' 9" - 5' 3" = 7' 6"

1. The first part of the paper is devoted to a general discussion of the problem of the existence of solutions of the system of equations (1) for arbitrary values of the parameters α and β . It is shown that the system has solutions for all values of the parameters α and β if the function $f(x)$ is continuous and has a bounded derivative. The second part of the paper is devoted to a detailed study of the properties of the solutions of the system of equations (1) for arbitrary values of the parameters α and β . It is shown that the solutions of the system of equations (1) are unique and depend continuously on the parameters α and β . The third part of the paper is devoted to a study of the asymptotic properties of the solutions of the system of equations (1) for large values of the parameters α and β . It is shown that the solutions of the system of equations (1) approach zero as the parameters α and β approach infinity.

APPENDIX M

ESTIMATED COST

A letter describing briefly the nature of work involved in the conversion was sent to four major shipbuilding companies in hopes of obtaining reliable cost estimates. A copy of this letter is presented at the end of this Appendix.

Two of the shipyards did not wish to be quoted directly, but replied with the following rough estimates:

"Two Million Dollars, Plus or Minus"

"a very rough estimate . . \$1,500,000.00"

A third shipyard was very much interested in the proposal and requested detailed information on the conversion so that their refined estimate would reflect the true nature of the conversion. To this end, arrangement plans and drawings were delivered to this concern, and they undertook a detailed estimate. Their estimate for the conversion is \$2,100,000.00 for each ship, requiring about 9 months for completion after award of contract. The detail and time that this company spent in preparation of this estimate far exceeded our initial request, and the cooperation by them could not be surpassed.

The fourth shipyard replied, "Your letter is having the attention of our engineering department. We expect to have some data from them shortly . . , and hope to get it to you in time for your presentation." Their estimate has not been received and is therefor not included.

In view of the fact that all estimates agree closely, the conversion should cost approximately One and One Half to Two Million Dollars. Some savings might be accomplished in labor and material by use of detailed procedures to bring about the full intent of this proposal; i.e. a least cost conversion. One particular item in this category would be time in dry dock.

A thorough investigation of the bow changes might show that this portion of the conversion could be accomplished outside of dry dock by using excessive trim by the stern. If it is possible to construct the new bow without supports while the ship is in the water, this would materially reduce the dry dock time, and a considerable cost savings made. Thus, dry dock time would be required only for the stern tube and shafting work, and underbody cleaning and painting which is definitely required prior to putting the ships in service.

Modest returns for this project would be realized in the financial return for the scrap, and the savings made by elimination of the maintenance cost for the scrapped vessel.

The fourth shipyard's final answer was received 25 May 1954. This reply contained detailed breakdown information so that we could make a very close estimate of cost. Since they requested that their breakdown not be made a matter of public information, only our estimate of cost from their detailed figures is given. Their information contained complete cost figures for the entire scope of work intended in the thesis, plus some additional work suggested by them for improving the intended conversion. From this data our estimate of a high-low range is \$1,100,000.00 to \$1,300,000.00.

The Commission has today issued a report which sets
out the results of its inquiry into the activities of the
various groups and individuals who are active in the
United States in connection with the Russian Revolution.
The Commission has found that the Russian Revolution
has been the cause of a great deal of trouble and
disturbance in the United States. It has found that
the Russian Revolution has been the cause of a great
deal of trouble and disturbance in the United States.
It has found that the Russian Revolution has been
the cause of a great deal of trouble and disturbance
in the United States. It has found that the Russian
Revolution has been the cause of a great deal of
trouble and disturbance in the United States.

Very truly yours,
[Signature]

18 April, 1954

Blank Shipbuilding Company

Gentlemen:

We have undertaken a thesis at M.I.T. concerning a conversion plan for Liberty Ships. Basically it is designed for two reasons. First, it may mean continued peace-time shipyard work for the shipbuilding industry, and second, it may be a solution for the U.S. Government to the pressing problem of "what to do with 1500 Liberty Ships, costing originally upwards of 6 billion dollars, having no real potential in case of emergency."

Our proposal is based on the following: For each ship scrapped, one would be modernized, using propulsion machinery obtained therefrom. Two additional boilers would be mounted forward of existing boilers (between frames 88 and 82). This would necessitate moving the existing forward engine room bulkhead from frame 88 to frame 81, also a new hatch must be made for hold #3, made smaller by this installation. Two main engines are to be located side by side, each 6' 6" from the centerline of the ship in the same longitudinal location. Single reduction gears for engine speed of 76 to 85 RPM of propeller are proposed. These are to be manufactured and installed with the following approximate sizes: 2 about 7 ft. Diam., 1 about 6 ft. Diam. New line shafting 15 $\frac{1}{4}$ in., tail shaft 17 in., stern tube and new 18' 0" propellers complete the major machinery changes. Necessary auxiliaries are to be duplicated by material from scrapped ship.

In addition to doubling the I.H.P. of the existing plant, the ship will be lengthened 24 ft. by addition of new bow faired into existing station #3, approximately frame 30. The new bow has cut-up, starting 53' 7" from the new forward perpendicular, raked stem and $\frac{1}{2}$ angle of entrance at 27 ft. W.L. of 16 degrees.

Our problem at the present time is to obtain a "snap estimate" of cost for inclusion in the final report. It is not the intention of the writers to promulgate any such information without the approval of the source, and the source will not be mentioned in the report by name. Thus, clearly, all we are after is a reasonable figure to either support or reject our proposal. Any information that you might be able to supply would be greatly appreciated and would be included in the thesis under any condition or restriction that you desire.

Thank you for your interest in this matter.

Yours truly,

APPENDIX N

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